



HORIZON-MISS-2021-CLIMA-02-01 - Development of climate change risk assessments in European regions and communities based on a transparent and harmonised Climate Risk Assessment approach

## **Risk and Vulnerability Assessment in Municipality of Rafina-Pikermi (RAFRVA)**

**Greece, Attica/Municipality of Rafina-Pikermi**

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## 5. Abbreviations and acronyms

Abbreviation / acronym	Description
RAFRVA	Risk and Vulnerability Assessment in Municipality of Rafina-Pikermi
EU	European Union
GIS	Geographic Information System
CRA	Climate Risk Assessment
DRM	Disaster Risk Management
EIA	Environmental Impact Assessment
KPIs	Key Performance Indicators
NOA	National Observatory of Athens
RCP	Representative Concentration Pathway
CMIP6	Coupled Model Intercomparison Project Phase 6
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRS	Coordinate Reference System
DEM	Digital Elevation Model
EPSG	European Petroleum Survey Group Code
GBA	Global Building Atlas
GCM	Global Climate Model
GIS	Geographic Information System
GLOFAS	Global Flood Awareness System
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
JJA	June–July–August
Med-CORDEX	Mediterranean Coordinated Regional Climate Downscaling Experiment
MedECC	Mediterranean Experts on Climate and Environmental Change
NOANN	National Observatory of Athens Network
OSM	OpenStreetMap
P10	10th Percentile
P25	25th Percentile
P50	50th Percentile (Median)
P75	75th Percentile
P90	90th Percentile
RCM	Regional Climate Model
RP	Return Period
SSP2-4.5	Shared Socioeconomic Pathway 2 – 4.5 W/m <sup>2</sup>
TN	Tropical Nights
TR	Tropical Nights Index
TX	Extreme Maximum Temperature Index
Tmax	Maximum Daily Temperature
Tmin	Minimum Daily Temperature
IDF	Intensity–Duration–Frequency

## 6. Executive summary

Phase 2 of the Climate Risk Assessment (CRA) for the Municipality of Rafina–Pikermi refines the multi-risk screening conducted in Phase 1 by integrating high-resolution local datasets, hydrological and coastal engineering studies, and local meteorological observations. The objective is to translate strategic risk screening into operationally relevant, municipality-scale risk information that supports civil protection planning.

Phase 1 identified flooding and heatwaves as priority hazards using European-scale datasets. Phase 2 confirms these priorities and explicitly quantifies hazard evolution under future climate conditions (RCP4.5), strengthening the forward-looking risk logic required by the CLIMAAX framework.

For heatwaves, local meteorological observations and downscaled projections indicate:

- Mean summer (JJA) maximum temperature increase of:
  - +1.1°C (2021–2040)
  - +2.4°C (2041–2060)
  - +3.6°C (2061–2080)
- Strong increase in tropical nights (minimum temperature > 26°C)
- Projected increase of ~20–25 additional days per year with  $T_{max} > 35^{\circ}\text{C}$  by late century

Night-time heat stress was identified as the dominant local hazard driver due to high humidity and low wind speeds, preventing physiological recovery. Risk is amplified by the municipality's role as the second largest passenger port in Greece, exposing large transient populations.

For flooding, Phase 2 refines the assessment by integrating local catchment evidence and authoritative technical documentation, including hydrolithological and drainage characteristics of the Megalo Rema system, observed rainfall extremes from local stations, projected intensity–duration–frequency (IDF) changes for short- and multi-day precipitation under RCP4.5, and coastal/wave studies relevant to the river mouth area. The findings indicate that structural bottlenecks and constrained channel sections along Megalo Rema can strongly amplify flood impacts during intense rainfall, while compound river–coastal interactions remain a credible mechanism near the outlet. In parallel, the projected intensification of short-duration precipitation increases the likelihood of flash flooding in a steep, rapidly responding catchment. On this basis, flood risk is assessed as substantial to critical in severity, requiring immediate action. Heatwave risk is assessed as substantial in severity, with rapidly increasing urgency and currently limited municipality-specific response capacity.

The Key Risk Assessment confirms:

- River and coastal flooding = highest priority risk (high severity, immediate urgency, medium resilience capacity)
- Heatwaves = high priority risk (substantial severity, increasing urgency, low–medium resilience capacity)

Phase 2 therefore moves from hazard identification to quantified, spatially explicit, and forward-looking risk prioritisation, directly supporting updates to municipal civil protection planning and adaptation strategies.

The refined results directly support:

- Identification of priority intervention areas;
- Improved definition of early warning and activation thresholds;
- Support for evacuation planning, safe access routes, and shelter allocation;
- Targeted protection of critical infrastructure and services, particularly in the port area;
- Enhanced coordination between municipal services during climate-related emergencies.

By moving from European-scale screening to a locally grounded, high-resolution, and prioritised risk assessment, Phase 2 significantly strengthens the Municipality of Rafina–Pikermi’s capacity to manage current and future climate risks. The outcomes of this phase provide a robust evidence base for updating civil protection plans, informing local adaptation strategies, and guiding future investments.

Overall, Phase 2 ensures that the CLIMAAX Climate Risk Assessment functions not only as an analytical exercise, but as a practical decision-support tool, contributing to improved preparedness, more effective emergency response, and enhanced long-term climate resilience for the municipality.

## 1 Introduction

### 1.1 Background

The Municipality of Rafina-Pikermi is a coastal urban region situated in Eastern Attica, Greece, approximately 30 kilometers east of Athens. The municipality encompasses an area of 40.501 km<sup>2</sup>, with a population of approximately 22,327 residents. Known for its proximity to the historical Marathon city and the scenic slopes of Mount Penteli, Rafina-Pikermi hosts the second busiest port in Attica, which annually facilitates travel for about two million passengers. The municipality is marked by a vibrant mix of densely populated urban areas and substantial ecological zones, including valuable riverbeds and coastal ecosystems. These natural features enhance the region’s environmental significance but simultaneously increase its susceptibility to climate-related hazards.

Over recent years, the municipality has faced escalating climate risks, notably highlighted by severe events such as the devastating wildfires of July 2018, commonly referred to as

the “Mati fire tragedy”, which tragically claimed more than 100 lives. This catastrophic event was intensified by gale-force western winds and prolonged drought conditions. Furthermore, Rafina-Pikermi has experienced multiple severe hydrometeorological events, including flash floods and intense storms. Examples of these include the Medicane “Xenophon/Zorbas” in September 2018, with wind gusts reaching up to 83 km/h, and Storm “Genesis” in June 2022, which led to significant flooding. The frequency, duration, and intensity of droughts and extreme precipitation events have notably increased over the past decades, exacerbating the existing vulnerability of the region.

The local infrastructure is currently challenged by an aging and inadequate water management system, insufficient drainage networks, and the legacy impacts of inadequate spatial planning and land management practices. The economic impacts of the Greek financial crisis further constrained the municipality’s resources, limiting effective emergency preparedness and adaptation strategies. Thus, the Rafina-Pikermi community is in urgent need of a comprehensive climate adaptation framework to enhance its resilience and safeguard its population, infrastructure, and ecological assets.

## 1.2 Main objectives of the project

Phase 2 of the Climate Risk Assessment builds on the harmonised, European-scale screening conducted in Phase 1 and aims to refine risk understanding at municipal scale using high-resolution local data and authoritative technical studies.

The objectives of Phase 2 are (a) to replace European-scale proxy datasets with locally validated hydrological, coastal, geological, and meteorological data, (b) quantify and spatially refine priority hazards, particularly river/coastal flooding and heatwaves, (c) explicitly integrate projected climate change signals into the risk assessment logic, (d) improve the representation of exposure and vulnerability at neighbourhood and infrastructure level, and (e) translate analytical outputs into operationally relevant inputs for municipal civil protection planning.

Phase 2 therefore moves from strategic hazard identification toward decision-oriented, spatially explicit, and forward-looking risk prioritisation.

## 1.3 Project team

The RAFRVA is coordinated and led by the Municipality of Rafina-Pikermi in collaboration with the environmental analytics and services company, METEOME. METEOME is specifically responsible for conducting climate hazard analyses, implementing risk assessment workflows, and ensuring rigorous scientific application of the CLIMAAX framework.

The project team involves close cooperation with municipal departments integral to climate risk management and urban development, notably civil protection and urban planning departments. Their local insights and sector-specific expertise are instrumental in

accurately defining and evaluating the regional climate risks and implementing appropriate adaptation strategies.

In addition, the project emphasizes active stakeholder engagement, capturing input and feedback from a diverse range of local actors. This comprehensive engagement ensures that the outcomes of the [RAFRVA](#) are locally relevant, broadly supported, and effectively integrated into the municipality's long-term adaptation and resilience strategies.

## 1.4 Outline of the document's structure

Following the introduction, Section 2 presents the Climate Risk Assessment Phase 2, including the scoping framework, stakeholder engagement, and the refinement of climate hazards, exposure, and vulnerability using local data and high-resolution models. This section also includes the regionalised risk analysis for priority hazards, the Key Risk Assessment (severity, urgency, resilience capacity, and risk prioritisation), as well as monitoring and evaluation aspects and the work plan for Phase 3. Section 3 summarises the main conclusions of Phase 2, highlighting key findings, challenges addressed and remaining limitations, and the added value of the refined, locally grounded risk assessment. The conclusions also outline how the results support improved civil protection planning and provide a foundation for local adaptation strategies and risk management actions. Supporting documentation and referenced technical studies are provided separately at the end of the document.

## 2 Climate risk assessment – phase 2

### 2.1 Scoping

#### 2.1.1 Objectives

The overall objective of the Climate Risk Assessment (CRA) Phase 2 for the Municipality of Rafina–Pikermi is to refine and enhance the climate risk analysis conducted in Phase 1, ensuring that the results are sufficiently detailed, accurate, and operational to support municipal-level decision-making and civil protection planning.

While Phase 1 focused on the identification and prioritisation of climate-related risks using harmonised European-scale datasets, Phase 2 aims to translate this strategic screening into locally grounded, decision-relevant knowledge. The assessment therefore places strong emphasis on the integration of high-resolution local data, authoritative studies, and context-specific information, in line with the guidance provided by the CLIMAAX framework.

The specific objectives of Phase 2 are to:

- Improve the representation of climate hazards by incorporating local-scale processes and dynamics that cannot be captured by European-scale proxy datasets.
- Refine exposure and vulnerability analysis through the use of detailed spatial information on population distribution, land use, infrastructure, and critical assets.

- Enhance the relevance of climate risk outputs for civil protection preparedness, emergency response, evacuation planning, and recovery actions.
- Provide an evidence base to support the update of existing municipal civil protection plans and to inform future local and regional planning instruments.

The expected outcome of the Phase 2 CRA is a robust, spatially explicit, and actionable assessment of climate risks that supports informed policy and operational decisions at the municipal level. The refined results are intended to feed directly into:

- Municipal civil protection and emergency management planning
- Local development and land-use planning processes
- Climate adaptation strategies and resilience-building measures
- Coordination with regional and national authorities responsible for flood risk management, civil protection, and infrastructure planning

By strengthening the link between climate risk analysis and policy implementation, Phase 2 contributes to the integration of climate resilience considerations into upcoming local and regional development plans, strategies, and sectoral policies, particularly in relation to flood risk management, heatwave response, and coastal zone protection.

Changes compared to Phase 1 scoping:

Compared to Phase 1, the scope of the CRA in Phase 2 has evolved in both depth and focus. While the priority hazards identified in Phase 1 (floods, heatwaves, and coastal flooding) remain unchanged, Phase 2 places particular emphasis on:

- Flood risk, especially flash and pluvial flooding mechanisms driven by the wider Rafina hydrological basin.
- The use of official local studies and engineering data to refine hazard pathways, critical locations, and impact mechanisms.
- The explicit translation of risk assessment results into civil protection-relevant outputs, rather than high-level risk indicators.

As a result, Phase 2 shifts from a broad screening exercise to a problem-oriented and solution-oriented assessment, tailored to the operational needs of the municipality.

The scope of the Phase 2 CRA is subject to several limitations and boundary conditions. These include:

- Variability in the availability, format, and temporal coverage of local datasets, particularly for socio-economic vulnerability indicators.
- Constraints related to the integration of legacy studies and maps produced for different purposes and at different times.
- Limited availability of quantitative impact data for past climate-related events, which restricts the calibration of certain risk indicators.

Several challenges and bottlenecks were encountered during the refinement process. These mainly concerned the harmonisation of heterogeneous datasets, differences in spatial resolution, and the need to interpret technical engineering documentation for use within a risk assessment framework.

In addition to data harmonisation challenges, important structural limitations were encountered in relation to the physical characteristics of the Rafina (Megalo Rema) river system and the availability of hydrological observations.

Megalo Rema is a relatively narrow, highly channelised river system with strong local hydraulic controls (bridges, culverts, engineered sections). Its width and morphological variability fall below the effective spatial resolution of most continental- or global-scale hydrological and flood hazard datasets. As a result, commonly used pan-European flood products and coarse-resolution hydraulic models are unable to realistically represent channel geometry, local constrictions, or rapid flow concentration mechanisms.

Furthermore, the absence of long-term local discharge (streamflow) monitoring stations within the Rafina basin significantly limits the feasibility of calibrating or validating fully dynamic hydraulic models for present or future conditions. Without reliable local flow measurements, quantitative projection of peak discharge under climate change scenarios would involve substantial uncertainty and risk of over- or under-estimation.

During Phase 2, several available datasets and modelling tools were evaluated, including regional-scale flood hazard products and climate-driven runoff simulations. However, these approaches did not provide physically realistic or spatially consistent estimates of future flood threat for the Megalo Rema system due to resolution constraints and lack of basin-specific calibration data.

For this reason, the assessment adopted a precautionary and evidence-based approach, relying on:

- Authoritative local hydrological documentation and precipitation return-period analyses
- Basin-scale delineation and tributary mapping of future extreme precipitation
- Coastal and wave penetration studies relevant to compound flooding
- Expert interpretation of structural bottlenecks and observed flood behaviour

This approach prioritises physical plausibility and operational relevance over model-derived numerical precision where calibration is not possible.

Where information was insufficient to fully answer specific guiding questions of the CLIMAAX framework, this has been explicitly acknowledged in the relevant sections of the assessment, in line with CLIMAAX guidance on transparency.

### 2.1.2 Context

Historically, the assessment and management of climate hazards and risks in the Municipality of Rafina–Pikermi have been characterised by a sectoral and largely reactive approach, focused primarily on post-event response rather than proactive risk reduction. Climate hazards such as flooding along the Rafina stream (Megalo Rema), heatwaves, wildfires, and coastal impacts have been recognised through individual studies, emergency response plans, and civil protection actions, but these efforts have not been systematically integrated into a comprehensive, multi-risk climate risk assessment framework.

Prior to the implementation of the CLIMAAX project, flood risk management in the area relied mainly on engineering studies and regulatory delineations of watercourses, while heat and wildfire risks were addressed through general civil protection guidelines and emergency protocols. These approaches, although valuable, did not fully account for the compound and cascading nature of climate risks, nor did they consistently incorporate climate change projections or vulnerability considerations.

Phase 1 of the CLIMAAX Climate Risk Assessment represented the first structured attempt to assess climate risks in Rafina–Pikermi using a harmonised methodological framework. Phase 2 builds upon this foundation by moving beyond high-level screening and addressing the need for greater spatial detail, local specificity, and operational relevance, particularly for hazards with rapid onset and complex local drivers.

The central problem addressed by the project is the increasing exposure and vulnerability of Rafina–Pikermi to climate-related extremes, driven by the combined effects of climate change, urban expansion, land-use pressures, aging infrastructure, and constrained municipal resources. These factors interact within a wider socio-environmental system that extends beyond municipal boundaries, especially in relation to hydrological processes, transport networks, and regional development dynamics.

Flood risk, in particular, is strongly influenced by upstream catchment processes that originate outside the administrative limits of the municipality, while heat stress is exacerbated by urban form, population density, and limited green infrastructure. These characteristics place Rafina–Pikermi within a broader regional risk system in Eastern Attica, where local impacts are shaped by regional-scale drivers and cumulative pressures.

Within the national and regional development context, these challenges reflect systemic issues faced by many Greek municipalities, including the long-term effects of economic constraints following the financial crisis, limited investment capacity for preventive infrastructure, and historical gaps in spatial planning enforcement. Phase 2 of the project explicitly situates local climate risks within this wider system, recognising that effective adaptation requires coordination across administrative levels and sectors.

The governance framework for climate risk assessment and management in Rafina–Pikermi is shaped by a combination of European Union, national, regional, and local policies and regulations. At the national level, Greece’s National Climate Change Adaptation Strategy and associated sectoral policies provide the overarching strategic direction for climate resilience. These are complemented by national civil protection legislation and guidelines that define responsibilities for preparedness, response, and recovery.

At the regional level, climate resilience initiatives and disaster risk reduction planning within the Attica Region influence priorities, funding opportunities, and coordination mechanisms. Local governance is further framed by spatial and urban planning legislation, environmental protection regulations, and municipal civil protection plans, which collectively determine how climate risk information can be operationalised.

Phase 2 of the CLIMAAX assessment is explicitly designed to strengthen the link between climate risk analysis and this governance framework, ensuring that refined risk information can be used to update civil protection plans, inform spatial planning decisions, and support compliance with legal and policy obligations.

Several sectors are particularly relevant in the context of climate risk in Rafina–Pikermi and are likely to be affected by climate change impacts. These include:

- **Civil protection and emergency management**, which must respond to increasingly frequent and intense extreme events.
- **Urban infrastructure and housing**, exposed to flooding, heat stress, and infrastructure failure.
- **Public health**, especially in relation to heatwaves and vulnerable population groups.
- **Transportation and mobility**, including port infrastructure that is critical for tourism, commerce, and emergency access.
- **Environmental management and ecosystems**, which influence flood regulation, microclimate conditions, and wildfire risk.
- **Local economic activities**, particularly tourism, fisheries, and small-scale agriculture, which are sensitive to climate variability and extremes.

Phase 2 refines the understanding of how these sectors are exposed and vulnerable by incorporating local-scale data and by explicitly linking sectoral impacts to climate hazard dynamics.

Climate risks in Rafina–Pikermi are influenced by several external factors and initiatives operating at regional, national, and European levels. These include regional climate adaptation planning in Attica, national disaster risk reduction strategies, and EU-funded projects aimed at strengthening climate resilience and sustainability. In addition, infrastructure developments and land-use changes in neighbouring municipalities can influence hydrological and environmental conditions within the Rafina basin.

Phase 2 recognises these interactions and seeks to align its findings with broader initiatives, enabling synergies in data use, planning coherence, and resource mobilisation.

Within this context, Phase 2 of the Climate Risk Assessment identifies a range of adaptation interventions that can contribute to meeting the project's objectives. These include:

- Strengthening early warning, preparedness, and emergency response mechanisms based on refined hazard and risk information.
- Improving flood risk management through targeted interventions informed by detailed hydrological and hydraulic analysis.
- Enhancing protection against heat stress through urban cooling measures, public health preparedness, and targeted support for vulnerable groups.
- Integrating climate risk considerations into spatial planning, infrastructure management, and environmental protection.
- Promoting awareness, coordination, and capacity building among municipal services and stakeholders.

At the time of the Phase 2 assessment, no municipality-specific civil protection protocols dedicated exclusively to heatwave events were available for Rafina–Pikermi. Heatwave preparedness and response are currently implemented in accordance with national civil protection guidelines, which provide a general framework for heatwave management applicable across Greek municipalities.

While national guidelines offer an essential baseline for preparedness and response, they are not tailored to the specific spatial, demographic, and infrastructural characteristics of individual municipalities. In the case of Rafina–Pikermi, factors such as population distribution, urban morphology, coastal influences, and the presence of vulnerable population groups create differentiated heat risk patterns that cannot be fully addressed through generic measures alone.

Phase 2 of the CLIMAAX Climate Risk Assessment addresses this gap by refining heat risk analysis using local data and by identifying municipality-specific priority areas, vulnerable groups, and operational needs. Based on the CLIMAAX results, the assessment proposes locally adapted heatwave preparedness and response guidelines that are fully aligned with national civil protection frameworks and are intended to complement, rather than replace, existing national procedures. These proposed guidelines aim to support the municipality in enhancing heatwave preparedness through targeted measures, improved coordination, and more effective protection of vulnerable populations.

### 2.1.3 Participation and risk ownership

Stakeholder involvement in Phase 2 of the CLIMAAX project was designed to build upon the results of Phase 1, ensure the relevance of the refined climate risk assessment, and support the translation of findings into practical civil protection and adaptation measures. Engagement focused on stakeholders with direct responsibilities in risk management, emergency response, social support, education, and economic activity in exposed areas.

Stakeholders were engaged primarily through targeted meetings and workshops, during which:

- The main findings of the Phase 1 Climate Risk Assessment were presented and discussed
- Priority hazards and exposed areas were validated against local experience
- Proposals developed during Phase 2, including refined flood and heat risk insights, were discussed with stakeholders
- Practical considerations for civil protection planning and preparedness were collected

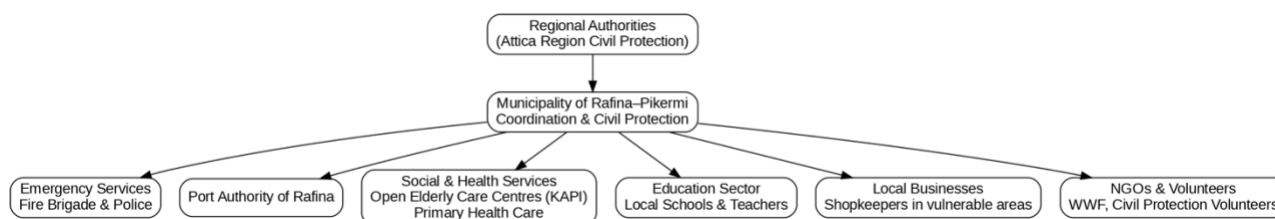
The following stakeholders actively participated in CLIMAAX-related meetings and workshops:

- **Municipality of Rafina–Pikermi**, including technical and administrative services
- **Port Authority of Rafina**, representing critical coastal and transport infrastructure
- **Local Police Department**, responsible for traffic management, public safety, and evacuation support
- **Local Fire Brigade Department**, responsible for emergency response, wildfire management, and flood-related operations
- **Educational community**, including teachers from local primary and secondary schools
- **Open Elderly Care Centres (KAPI)**, representing elderly and socially vulnerable populations
- **Local shopkeepers and business representatives** from flood-prone and high-exposure areas
- **Non-governmental organisations**, including WWF, contributing expertise on environmental protection and climate adaptation
- **Municipal social services**, responsible for vulnerable population support and welfare
- **Primary healthcare representatives**, particularly in relation to heatwave impacts on public health
- **Civil Protection volunteers** and local volunteer groups
- **Regional-level civil protection representatives** (Attica Region), providing coordination and policy alignment

Stakeholder roles and responsibilities can be conceptualised as an interconnected system centred on the municipality:

- The Municipality of Rafina–Pikermi acts as the coordinating body for local preparedness, response, and recovery.
- Emergency services (Fire Brigade, Police) operate in close coordination with municipal civil protection structures.
- The Port Authority functions as a critical infrastructure operator with strong interdependencies with municipal emergency planning.

- Social services, elderly care centres, schools, and healthcare representatives act as intermediaries for vulnerable groups.
- Local businesses and NGOs provide contextual knowledge, local impact insight, and support awareness-raising and resilience actions.
- Regional authorities provide strategic coordination, guidance, and access to broader planning and funding mechanisms.



**Fig. 2.1.3** Stakeholder organigram illustrating participation and risk ownership in the CLIMAAX Phase 2 Climate Risk Assessment for the Municipality of Rafina–Pikermi.

Risk ownership in Rafina–Pikermi follows the institutional framework defined by national civil protection legislation and is shared across multiple governance levels.

- Risk identification and assessment are supported by national authorities and research initiatives, while municipalities are responsible for applying risk information at the local level.
- Preparedness, response, and mitigation actions fall primarily under the responsibility of the municipality, in coordination with emergency services.
- Flood risk management involves coordination with regional and national authorities due to the scale of hydrological systems.
- Heatwave preparedness is guided by national civil protection protocols, with municipalities responsible for local implementation and support measures.
- Wildfire risk is managed primarily by the Fire Brigade, with municipal support for prevention, evacuation, and recovery.

Phase 2 of the CLIMAAX project strengthens risk ownership by clarifying responsibilities, improving local risk knowledge, and supporting evidence-based decision-making.

Representatives of known vulnerable groups were included in the stakeholder engagement process, either directly or through institutional intermediaries. These include:

- Elderly populations, represented through Open Elderly Care Centres
- School-age children and educational staff
- Residents and businesses located in flood-prone or highly exposed areas
- Coastal users and workers linked to port operations

Their participation ensured that local knowledge and lived experience informed the refinement of risk assessment and the identification of practical adaptation needs.

At the municipal level, formal quantitative thresholds defining acceptable or tolerable climate risk are not explicitly established. Risk acceptability is therefore implicitly defined through national civil protection standards, legal obligations, and operational practices.

Within this context, Phase 2 of the CLIMAAX assessment contributes by:

- Providing clearer spatial identification of high-risk areas
- Supporting prioritisation of intervention zones and vulnerable groups
- Enabling more informed judgement on risk reduction needs and acceptable residual risk

#### 2.1.4 Application of principles

The Phase 2 was conducted in accordance with the core principles outlined in the CLIMAAX Framework. These principles guided both the methodological choices and the interpretation of results, ensuring that the assessment is robust, inclusive, and suitable for supporting evidence-based decision-making under conditions of uncertainty.

- Social justice, equity, and inclusivity

Considerations of social justice, equity, and inclusivity were integrated throughout the assessment by explicitly recognising that climate risks do not affect all population groups equally. Phase 2 placed particular emphasis on identifying vulnerable and priority groups, including elderly populations, school-age children, residents and businesses located in flood-prone areas, and users of critical coastal and transport infrastructure.

Stakeholder engagement activities included representatives of these groups either directly or through institutional intermediaries, such as Open Elderly Care Centres, schools, local businesses, and social services. This ensured that local knowledge and lived experience informed the refinement of risk analysis and the identification of adaptation needs.

Where municipality-specific preparedness measures were not available (for example, in relation to heatwave response), the assessment explicitly identified these gaps and used the CLIMAAX results to propose locally adapted guidance that complements national frameworks. In this way, the assessment supports more equitable protection by promoting targeted measures for groups and areas that are disproportionately exposed to climate risks.

- Quality, rigour, and transparency

Quality and scientific rigour were ensured through the systematic application of the CLIMAAX methodological framework and through the use of authoritative, high-resolution local data in Phase 2. Compared to Phase 1, the assessment benefits from improved spatial detail, better representation of local hazard mechanisms, and clearer differentiation of exposure and vulnerability patterns.

All data sources, assumptions, and methodological choices are documented transparently. Where data limitations, uncertainties, or inconsistencies were encountered, these are explicitly acknowledged and discussed in the relevant sections of the report. The integration of heterogeneous datasets was supported by expert judgement and consistent spatial processing, ensuring internal coherence while maintaining traceability.

By clearly stating what has changed compared to Phase 1 and by documenting remaining uncertainties, Phase 2 enhances the credibility and usability of the climate risk assessment for both technical and non-technical audiences.

- Precautionary approach

A precautionary approach was adopted throughout Phase 2, recognising that climate change introduces significant uncertainty and that waiting for complete or perfect information may delay necessary action. In situations where quantitative data were limited or where local thresholds for acceptable risk were not explicitly defined, the assessment prioritised risk awareness, transparency, and early action.

The refined analysis focuses on identifying areas and systems where potential impacts could be severe or irreversible, such as densely populated flood-prone zones, critical infrastructure, and vulnerable population groups. By highlighting these areas, the assessment supports proactive planning and preventive measures, even where uncertainties remain.

The precautionary principle is further reflected in the emphasis on strengthening preparedness, early warning, and civil protection capacity, rather than relying solely on post-event response. This approach aligns with the CLIMAAX objective of supporting climate-resilient decision-making under conditions of uncertainty.

#### 2.1.5 Stakeholder engagement

- Engagement approach and activities

Stakeholders were engaged primarily through targeted meetings and workshops, complemented by bilateral exchanges and follow-up communications. These activities built on the stakeholder network established in Phase 1 and were structured around two main objectives: (a) presentation and validation of Phase 1 results, and (b) discussion of refined analyses and proposed measures developed during Phase 2.

During Phase 2, the following engagement activities were carried out:

- Workshops presenting Phase 1 Climate Risk Assessment results, with emphasis on priority hazards and exposed areas.
- Focused meetings during Phase 2, where refined flood and heat risk insights were presented and discussed.

- Informal consultations and follow-up exchanges to clarify data needs, local practices, and operational constraints.
  - Sharing of maps, summaries, and key messages to support understanding and facilitate feedback.
- Participants

Participants in stakeholder meetings and workshops included:

- Municipal representatives and technical services of Rafina–Pikermi
- Emergency services, including the local Fire Brigade and Police Department
- The Port Authority of Rafina
- Representatives of Open Elderly Care Centres (KAPI)
- Teachers and representatives from local schools
- Local shopkeepers and business representatives from vulnerable areas
- Non-governmental organisations, including WWF
- Civil protection volunteers and social service representatives

This ensured participation from both institutional actors and priority groups, in line with the project's stakeholder engagement commitments.

- Communication of project goals and results

Project goals, intermediate results, and Phase 2 refinements were communicated through:

- Structured presentations during workshops and meetings
- Visual materials, including maps and diagrams illustrating hazard and risk patterns
- Plain-language explanations of key findings and uncertainties
- Discussions linking analytical results to practical civil protection and adaptation implications

Communication focused on clarity, transparency, and relevance, ensuring that technical content was accessible to non-technical participants while maintaining scientific credibility.

- Reception of results and feedback

Overall, the results of the Climate Risk Assessment were received positively by participants, who recognised the added value of the refined, local-scale analysis compared to previous approaches. Stakeholders particularly appreciated:

- The improved spatial detail of flood risk information
- The explicit consideration of vulnerable groups and priority areas
- The focus on practical implications for preparedness and response

Feedback from participants highlighted the importance of:

- Locally adapted preparedness measures, especially for heatwaves
- Clear prioritisation of intervention areas
- Continued coordination between municipal services and external stakeholders

This feedback informed the refinement of Phase 2 outputs and the formulation of proposed guidelines and recommendations.

- Use of project outcomes by participants

The outcomes of the CLIMAAX Phase 2 assessment are intended to be used by participants to:

- Support updates to municipal civil protection and emergency response plans
- Inform preparedness activities and coordination among emergency services
- Enhance awareness of climate risks among vulnerable groups and local actors
- Support alignment with regional and national climate adaptation and civil protection initiatives

By providing an evidence-based and locally relevant risk assessment, the project enables stakeholders to integrate climate risk considerations into their respective areas of responsibility.

- Difficulties encountered

Several challenges were encountered during stakeholder engagement in Phase 2. These included:

- Limited availability of some stakeholders due to operational responsibilities
- Variability in technical background among participants
- Constraints related to time, resources, and scheduling

These challenges were addressed by adopting a flexible engagement approach, using targeted meetings rather than large-scale events, and by providing follow-up explanations and materials where needed.

## 2.2 Risk Exploration

### 2.2.2 Screen risks (selection of main hazards)

Phase 1 screened a broad set of climate-related hazards for Rafina–Pikermi using harmonised European-scale datasets and identified flooding, heatwaves, and coastal flooding as priority concerns. In Phase 2, the *screening conclusions remain broadly consistent*, but the step has been refined in three important ways:

1. **Flood risk** is re-characterised more explicitly as a flash/pluvial-dominated risk, strongly driven by upstream catchment processes and local hydraulic constraints, based on authoritative local hydrological and hydraulic documentation.
2. **Heat risk** is reframed as a preparedness and public-health planning issue, acknowledging that the municipality currently implements national civil protection guidance and (at the time of the assessment) did not provide dedicated municipality-specific heatwave protocols; therefore, Phase 2 uses CLIMAAX results to propose locally adapted guidance aligned with national frameworks.
3. **Coastal flooding/storm surge** is retained as a critical risk for the coastal front and port system, with emphasis on continuity of operations, emergency access, and disruption to mobility and services.

The hazards most relevant to Rafina–Pikermi and repeatedly emphasised by stakeholders and past impacts are:

- **Flooding** (flash flooding, pluvial flooding, and riverine flooding along the Rafina stream / Megalo Rema): risks include rapid inundation of built-up areas, disruption of road access, impacts on critical facilities, and cascading effects on emergency response capacity. The Phase 2 screening is strengthened by local basin delineation, tributary network mapping, and identification of hydraulic structures and constrictions.
- **Heatwaves and heat stress**: risks include impacts on public health (especially elderly and sensitive groups), reduced labour productivity, and stress on municipal services. The Phase 2 approach prioritises locally relevant operational measures and the identification of priority groups and areas for intervention.
- **Coastal flooding and storm surge**: risks include impacts on the coastal zone, port-related infrastructure and access routes, and disruption to transport and emergency operations.

Flooding concentrates along the main watercourse and tributary network of the Rafina basin, including areas where channel capacity and hydraulic structures (bridges, culverts, channelised segments) may create local bottlenecks. The local mapping set used in Phase 2 explicitly depicts catchment boundaries, tributaries, and key structural elements, allowing a much clearer identification of exposed corridors and priority sections for operational planning.

Heat stress affects the municipality more broadly, with higher concern for elderly populations and people with pre-existing health conditions, as well as schools and outdoor workers during peak summer conditions.

Coastal hazards affect low-lying coastal areas and the port system, with potential impacts on mobility, commerce, and emergency access.

A review of Copernicus Climate Change Service information for southeastern Europe and the Mediterranean indicates a consistent hazard signal relevant to Rafina–Pikermi:

- Increasing heat stress and heatwave conditions across southeastern Europe, with recent Copernicus reporting highlighting record heat stress conditions and persistent heat and drought patterns in the region.
- Elevated coastal and marine risks in the Mediterranean, including warming seas and sea level rise, which increase the likelihood and consequences of coastal flooding when combined with storm events.

These Copernicus findings support the continued prioritisation of heat and coastal risks and reinforce the importance of robust preparedness for compound extremes.

Based on Phase 1 prioritisation, stakeholder input, and the availability of high-resolution local evidence, Phase 2 covers the following hazards in depth:

1. **Flood risk** (primary refinement focus): selected because (a) it is repeatedly experienced and operationally critical, and (b) Phase 2 introduces substantial new local evidence that materially improves hazard representation (catchment/sub-catchments, hydrographic network, structural constraints).
  2. **Heat risk** (preparedness-focused refinement): selected due to growing heat stress signals and the direct relevance to public health and civil protection planning; Phase 2 translates risk findings into locally adapted guidance aligned with national procedures.
  3. **Coastal flooding/storm surge** (targeted refinement): selected due to the port's criticality and potential disruption to emergency access and local economy, especially under conditions of rising sea levels and marine extremes.
- Available knowledge/data and further needs

Key local data now available and used in Phase 2 (new compared to Phase 1):

- Local hydrological basin delineation, and sub-basin structure for the Rafina stream system, enabling a significantly improved flood screening and subsequent risk analysis.
- High-resolution GIS layers of the buildings affected by floods, and a structured inventory of flood “hotspots” from municipal operations.

### 2.2.3 Choose Scenario

Future climate conditions in Phase 2 were assessed using the intermediate greenhouse gas concentration pathway RCP4.5 (approximately equivalent to SSP2-4.5 in the CMIP6 framework). This scenario represents a stabilisation pathway under moderate emissions reductions and is widely applied in European and Mediterranean climate risk assessments as a central planning reference scenario.

The selection of RCP4.5 is supported by recent scientific assessments. The IPCC Sixth Assessment Report identifies SSP2-4.5 as a “middle-of-the-road” pathway reflecting current global policy trajectories and socio-economic development patterns, positioned between strong mitigation and very high emissions scenarios (IPCC, 2021; IPCC, 2022). Observed global temperature evolution to date is consistent with intermediate warming pathways, and projected near-term warming under SSP2-4.5 closely matches current emission trends (IPCC, 2021).

The Mediterranean region is recognised as a climate change hotspot, with warming rates exceeding the global average and pronounced sensitivity to heat extremes, hydrological variability, and sea-level rise (MedECC, 2020; IPCC, 2021). Even under intermediate emission scenarios, regional projections indicate substantial increases in the frequency and duration of extreme heat events, intensification of heavy precipitation episodes despite potential decreases in total annual rainfall, and continued sea-level rise contributing to elevated coastal flood risk (IPCC, 2021; IPCC, 2022).

Recent European assessments further confirm that Southern Europe is already experiencing a strong upward trend in heatwave intensity and compound climate extremes, with projections under SSP2-4.5 indicating continued escalation over the coming decades (EEA, 2023; Copernicus Climate Change Service, 2023). These trends are particularly relevant for Eastern Attica, where rising summer temperatures, short-duration rainfall extremes, and coastal exposure interact with local geomorphological constraints.

Given this evidence, RCP4.5 represents a scientifically robust and policy-relevant scenario for municipal-scale adaptation planning. It captures climate risks that are already emerging and expected to intensify in the short- and medium-term horizons relevant for civil protection and infrastructure planning. Importantly, the IPCC demonstrates that substantial increases in heat extremes and heavy precipitation occur even under intermediate pathways, reinforcing the need for precautionary adaptation measures (IPCC, 2021).

The use of RCP4.5 in this assessment is therefore consistent with current scientific consensus, regional climate dynamics in the Mediterranean basin, and standard European practice in climate risk assessment.

## 2.3 Regionalized Risk Analysis

### 2.3.1 Hazard #1 Heatwaves

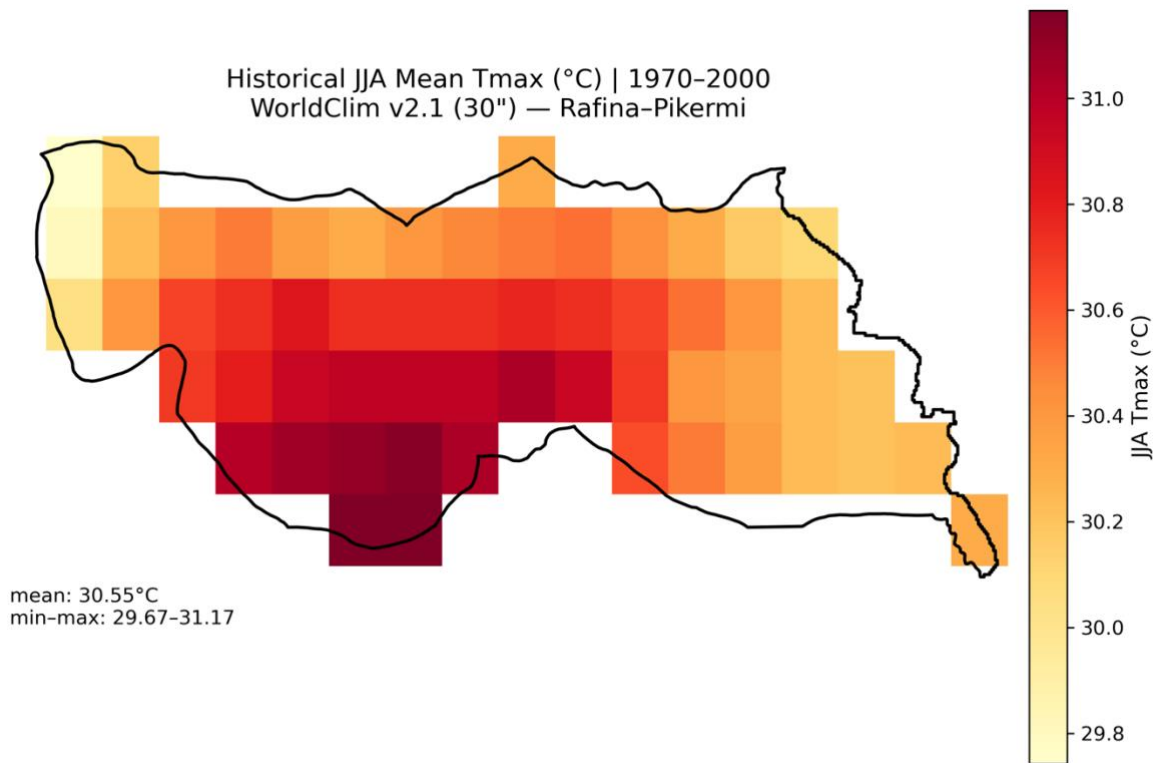
Table 2.3a Data overview workflow #1

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
NOA / meteo.gr (historical weather station data – temperature, timeseries 2014-2023)	Demographic structure (hospitals, schools, care centres)	Residential areas, schools, public buildings, bus stops	Heat risk priority areas; identification of population groups requiring targeted heatwave preparedness
WorldClim v2.1 high-resolution gridded data (30 arc-seconds)		Global Building Atlas (3x3 m)	
EURO-CORDEX / MED-CORDEX ensemble projections (bias-corrected)		WorldPop	

#### 2.3.1.1 Hazard assessment

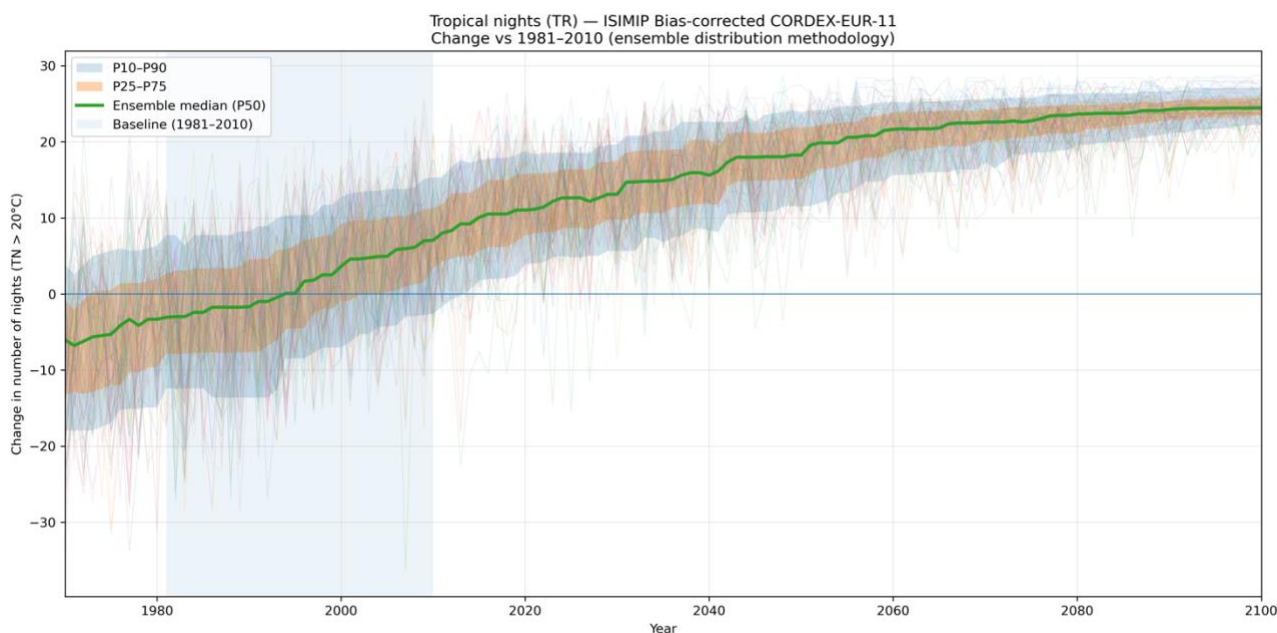
The heatwave hazard assessment for the Municipality of Rafina–Pikermi integrates multiple complementary climate datasets in order to ensure both observational robustness and forward-looking consistency. Historical heat conditions were characterised using local meteorological station data for the period 2014–2023, providing recent high-frequency observations of maximum temperature, heatwave duration, and nocturnal thermal persistence. These observations were used to validate spatial patterns and contextualise recent heat extremes within the broader regional warming trend observed across the Mediterranean basin (IPCC, 2021; Copernicus Climate Change Service, 2023).

Future climate evolution was assessed using high-resolution downscaled projections from WorldClim v2.1 based on CMIP6 global climate models under the SSP2-4.5 pathway, representing the ensemble mean of 13 models for the period 2021–2080 (Fick & Hijmans, 2017; WorldClim v2.1 documentation). The 30 arc-second (~1 km) spatial resolution enables grid-point level analysis within the municipal boundary, preserving local temperature gradients and coastal–inland contrasts relevant for heat exposure.



**Fig. 2.3.1.a** Spatial distribution of mean June–July–August (JJA) daily maximum temperature (°C) for the historical baseline period 1970–2000 derived from WorldClim v2.1 (30 arc-second resolution). The map represents the climatological average across CMIP6 ensemble means downscaled to approximately 1 km resolution.

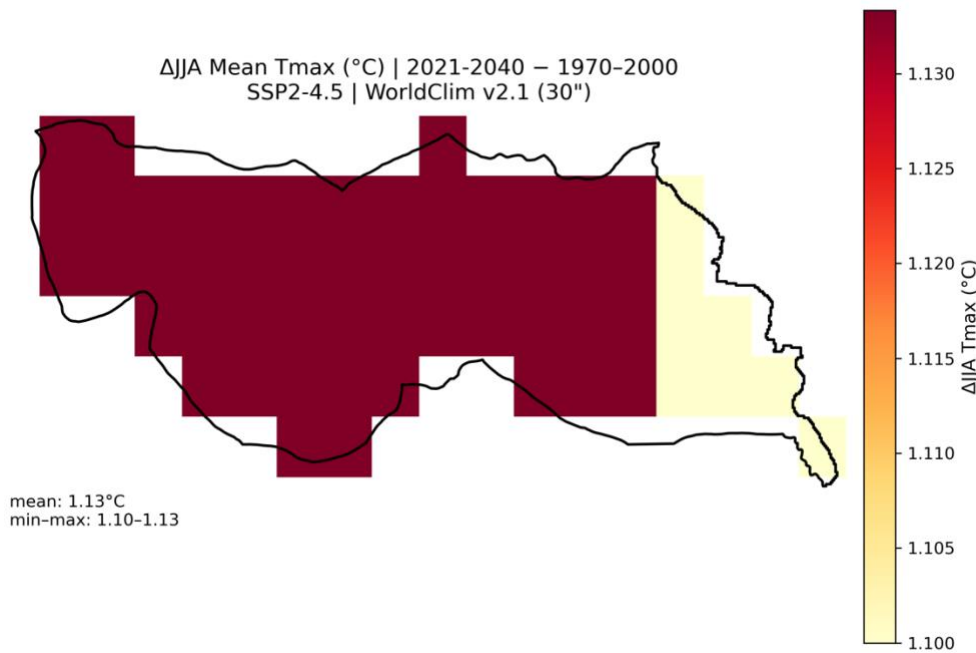
To explicitly capture changes in extreme heat indicators and inter-model uncertainty, bias-corrected regional climate model outputs from the Med-CORDEX initiative (ISIMIP bias-adjusted CORDEX-EUR-11 ensemble, 1970–2100) were also employed (Jacob et al., 2014; Lange, 2019). The use of regional climate models allows improved representation of Mediterranean-scale processes, including land–sea interactions and regional atmospheric circulation patterns, which are critical drivers of heatwave development in Eastern Attica (MedECC, 2020).



**Fig. 2.3.1b** Projected change in annual number of tropical nights (TN > 20°C) relative to the 1981–2010 baseline derived from the ISIMIP bias-corrected CORDEX-EUR-11 ensemble. The green line represents the ensemble median (P50), while shaded areas denote inter-model uncertainty ranges (P25–P75 and P10–P90). The grey band indicates the historical baseline period.

Observed meteorological data from the Rafina (coastal) and Pallini (inland – less than 4 km distance west from Pikermi) stations (NOANN, Lagouvardos et al., 2017) indicate that the area is already exposed to recurrent summer heat stress. Over the 2014–2023 period, the mean June–July–August (JJA) daily maximum temperature reached 31.5°C in Pallini and 29.3°C in Rafina, demonstrating an inland amplification of approximately 2.2°C in daytime summer temperatures. The difference reflects reduced marine moderation inland. Extreme hot days, defined as Tmax exceeding 35°C, occur on average 9.2 days per year in Pallini and 2.9 days per year in Rafina. However, recent extreme years (notably 2021 and 2023) recorded substantially higher exceedances, confirming increasing variability and episodic amplification. Tropical nights, defined as Tmin exceeding 20°C, occur with high frequency at both stations, averaging approximately 82 nights per year. Notably, coastal Rafina does not exhibit a meaningful reduction in tropical nights relative to inland Pallini, indicating limited nocturnal cooling capacity across the municipality.

Future climate projections from WorldClim v2.1 (30 arc-second resolution, SSP2-4.5 scenario) show a clear and spatially coherent increase in mean summer maximum temperature. Relative to the 1970–2000 baseline (mean JJA Tmax ≈ 30.5°C), the municipality is projected to experience an increase of approximately +1.1°C in the 2021–2040 period, +2.3°C in 2041–2060, and up to +3.5°C by 2061–2080. This progressive warming indicates that present-day extreme summers are likely to become climatologically normal conditions by mid-century.



**Fig. 2.3.1c** Projected change ( $\Delta$ ) in mean JJA daily maximum temperature ( $^{\circ}\text{C}$ ) for 2021–2040 relative to 1970–2000 under SSP2-4.5, derived from WorldClim v2.1 (CMIP6 ensemble mean, 30 arc-second resolution).

While mean warming provides the background climate shift, Med-CORDEX regional climate ensemble projections allow assessment of threshold-based extremes. The ensemble median indicates an increase of approximately 10–13 additional days per year exceeding  $35^{\circ}\text{C}$  in the 2021–2040 period relative to 1981–2010. This increase rises to approximately 15–20 additional days by mid-century and more than 22–25 additional days by 2061–2080. When combined with current observed exceedance rates, inland areas such as Pallini could experience 20–25 extreme hot days annually by mid-century, while coastal Rafina may experience 15 or more such days. This represents a structural shift in heat exposure rather than isolated episodic extremes.

Similarly, tropical nights are projected to increase substantially. Ensemble median projections indicate approximately +12 additional tropical nights per year in the near-term period, +18 by mid-century, and up to +25 by late century. Given the current baseline of approximately 82 tropical nights per year, this suggests that annual counts could exceed 100 nights per year by mid-century. The increase in nocturnal heat is particularly critical because it reduces physiological recovery, increases cooling demand, and elevates cumulative thermal stress.

The consistency between mean warming projections (WorldClim) and threshold exceedance projections (Med-CORDEX) strengthens the robustness of the hazard assessment. The projected increase in extreme hot days is non-linear relative to mean warming. A  $+1^{\circ}\text{C}$  increase in mean summer temperature corresponds to approximately 10 additional days above  $35^{\circ}\text{C}$ , while warming beyond  $+2^{\circ}\text{C}$  results in disproportionate

expansion of the upper tail of the temperature distribution. This tail amplification is characteristic of Mediterranean climates under warming conditions (IPCC, 2021).

Overall, the Rafina–Pikermi area is transitioning from a regime characterized by episodic severe heat events to one characterized by sustained and intensifying thermal stress. Inland areas are expected to experience stronger daytime amplification, while nighttime stress is projected to increase uniformly across the municipality. Under SSP2-4.5, heatwave hazard severity should be considered high and rapidly intensifying, particularly beyond 2040.

According to Table 2.3.1, heatwave hazard severity is classified as high based on:

- Mean summer warming exceeding +2°C by mid-century under SSP2-4.5;
- Projected increase of >20 days/year with T<sub>max</sub> >35°C by 2061–2080;
- Increase of >20 additional tropical nights/year;
- Persistent night-time minimum temperatures >26°C during extreme events.

These thresholds represent structural changes in baseline summer conditions rather than episodic anomalies and correspond to upper-tier Mediterranean heat stress regimes (IPCC, 2021; MedECC, 2020).

Table 2.3.1– Summary of Observed and Projected Heat Hazard Indicators (Rafina–Pikermi)

INDICATOR	OBSERVED (2014–2023)	2021–2040	2041–2060	2061–2080
<b>MEAN JJA TMAX (°C)</b>	29.4 (Rafina) / 31.5 (Pallini)	+1.1°C vs 1970–2000	+2.3°C	+3.5°C
<b>DAYS TMAX &gt; 35°C</b>	2.9 (Rafina) / 9.2 (Pallini)	+10–13 days	+15–20 days	+22–25 days
<b>TROPICAL NIGHTS (TMIN &gt; 20°C)</b>	~82 nights/year	+12 nights	+18 nights	+23–25 nights

*Future values represent changes relative to historical baselines (1970–2000 for mean temperature; 1981–2010 for threshold indices).*

The projected transition implies that present-day extreme summers (e.g., 2021, 2023) become climatologically average by mid-century. This represents a regime shift rather than incremental variability.

### 2.3.1.2 Risk assessment

The heatwave risk assessment for the Municipality of Rafina–Pikermi combines the refined local heatwave hazard characterisation presented in Section 2.3.1.1 with information on population exposure, vulnerable groups, and urban characteristics. Risk is understood as

the interaction between heatwave intensity and persistence, exposure of people and assets, and vulnerability related to demographic, social, and functional factors.

- Exposure of population and urban environment

Rafina–Pikermi is exposed to significant heatwave risk due to a combination of permanent population, seasonal population increase, and intensive human activity during summer months. Residential areas, commercial zones, and public spaces are all subject to prolonged exposure during heatwave periods.

While Rafina benefits from its coastal location and the moderating influence of Etesian (Meltemi) winds during daytime hours, this mitigating factor does not fully offset heat risk, particularly during prolonged heatwave events and under night-time conditions, when ventilation is reduced.

Urban characteristics such as building density, limited green spaces in certain areas, and heat retention by the built environment further contribute to elevated exposure.

Several population groups are particularly vulnerable to heatwave impacts in Rafina–Pikermi:

- Elderly residents (65–90), especially those with chronic health conditions;
- Children, particularly in educational and recreational settings;
- Tourists and short-term visitors, many of whom are not acclimatised to high heat and humidity;
- Outdoor workers, including port staff, transport workers, and service personnel.

The presence of Elderly Care Centres, schools, and other sensitive facilities within the municipality increases the importance of targeted heatwave preparedness and response measures.

A key risk driver identified in Phase 2 is the persistence of high night-time temperatures and humidity, resulting in tropical nights during heatwave periods. Local observations and modelling provided by the National Observatory of Athens indicate that night-time temperatures frequently do not fall below 26 °C, while relative humidity increases and wind speeds decrease.

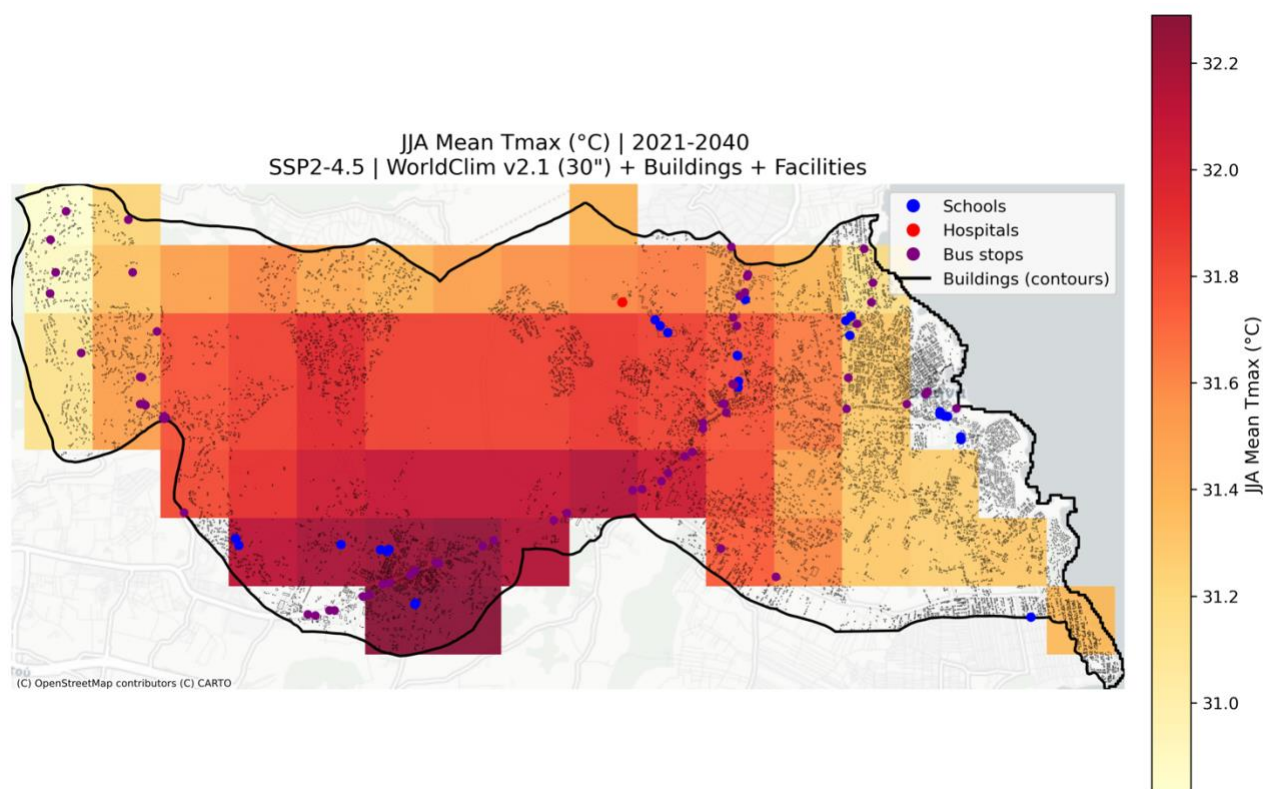
These conditions lead to very high heat index values during night-time hours, preventing physiological recovery and resulting in cumulative heat stress over successive days. This significantly elevates health risks, particularly for vulnerable groups, and increases the likelihood of heat-related illness even in the absence of extreme daytime temperatures.

Night-time heat stress represents a critical amplification of heatwave risk and is especially relevant for residential areas, accommodation facilities, and public spaces where cooling options may be limited.

The refined hazard assessment presented in Section 2.3.1 demonstrates that mean summer (JJA) maximum temperature is projected to increase by approximately +1.1°C in

the 2021–2040 period under SSP2-4.5. This warming is spatially uniform across the municipality, with inland areas (particularly Pikermi) exhibiting slightly higher projected temperatures compared to coastal Rafina due to reduced marine moderation.

The spatial distribution of projected warming and its intersection with the built environment and critical facilities is illustrated in Fig. 2.3.1d.



**Fig. 2.3.1d** Spatial distribution of projected mean summer (JJA) maximum temperature (°C) for 2021–2040 under SSP2-4.5 (WorldClim v2.1, 30 arc-second resolution), overlaid with building footprints and critical facilities in the Municipality of Rafina–Pikermi. Building footprints (black contours) represent 13,912 structures. Blue points indicate schools, red points hospitals, and purple points bus stops.

The +1.1°C increase in mean summer temperature affects the entire municipal territory. Consequently:

- All 22,327 residents are exposed to elevated baseline summer temperatures.
- All 13,912 mapped buildings operate under warmer thermal conditions, including non-air-conditioned educational facilities.
- Critical facilities, including schools, healthcare facilities, and public transport nodes, fall within grid cells experiencing projected warming.

Although +1.1°C may appear moderate, this represents a structural upward shift of the summer baseline. Present-day above-average summers are projected to become climatologically normal conditions by 2040. This implies that even in the absence of extreme events, the municipality will experience persistently higher background heat stress.

Exposure is not spatially homogeneous. Inland Pikermi exhibits higher projected JJA T<sub>max</sub> values relative to coastal Rafina. This inland amplification increases daytime heat accumulation and cooling demand in residential neighbourhoods located away from marine airflow influence.

Public transport infrastructure represents a micro-scale heat exposure hotspot (see bus stops in Fig. 2.3.1d). Bus stops, particularly those lacking shading or reflective materials, expose waiting passengers to direct solar radiation and high surface temperatures during peak afternoon hours. Given the projected increase in extreme hot days (+10–13 days above 35°C by 2021–2040) and additional tropical nights, exposure at bus stops may occur under both daytime and early evening high-heat conditions. Elderly residents and school-aged children are disproportionately affected due to mobility dependence and limited thermoregulatory capacity.

In addition to the permanent population, seasonal exposure increases substantially during summer due to tourism and port-related passenger flows. As the second largest passenger port in Greece, Rafina hosts high transient population volumes during peak heat periods, amplifying cumulative exposure.

Heatwave vulnerability is strongly age-dependent and socially differentiated. Based on WorldPop-derived demographic structure, approximately 3,450 residents aged 65–90 years reside within the municipality. This cohort represents roughly 15% of the total population and constitutes the most physiologically vulnerable group to heat stress.

This age group will experience:

- Approximately +12 additional tropical nights per year by 2021–2040 relative to baseline;
- A projected increase of 10–13 additional days per year exceeding 35°C in the near term;
- Further escalation beyond 2040, with tropical nights potentially exceeding 100 per year by mid-century.

Tropical nights (T<sub>min</sub> >20°C) are particularly critical for this group. Current observations already indicate approximately 82 tropical nights per year. Under SSP2-4.5, this may increase to ~94 nights annually by 2021–2040 and substantially more thereafter.

Night-time minimum temperatures frequently remain above 26°C during extreme episodes, combined with elevated humidity and reduced wind speeds. These conditions prevent physiological recovery between hot days and significantly increase cumulative cardiovascular and respiratory stress. For elderly populations, this mechanism is a primary mortality driver during Mediterranean heatwaves.

The risk escalation is not limited to mean warming. Regional climate model projections (Med-CORDEX ensemble) indicate:

- +10–13 additional days per year with T<sub>max</sub> >35°C by 2021–2040;
- +15–20 additional extreme hot days by mid-century;
- +22–25 additional extreme hot days by 2061–2080.

This expansion of the upper tail of the temperature distribution implies non-linear amplification of health risk. A modest shift in mean temperature produces a disproportionate increase in extreme heat exposure.

As a result, heatwaves transition from episodic stress events to sustained seasonal pressure.

- Implications for Rafina as a major passenger port

The night-time heat stress hazard is particularly significant for Rafina due to its role as the second largest passenger port in Greece, serving large numbers of travellers during the summer season. Tourists and passengers often experience prolonged exposure to heat stress:

- During late-evening and night-time arrivals or departures;
- While waiting in port areas with limited shading or cooling;
- In accommodation and urban environments where night-time cooling is insufficient.

The combination of high night-time temperatures, elevated humidity, and reduced wind creates conditions of very high heat index, increasing the vulnerability of non-acclimatised populations, elderly travellers, and individuals with pre-existing health conditions.

Based on the integration of refined hazard data, exposure patterns, and vulnerability factors, heatwave risk in Rafina–Pikermi is assessed as high, particularly during prolonged summer heat events. The risk is driven not only by peak daytime temperatures, but critically by night-time heat stress, cumulative exposure, and the presence of vulnerable and transient populations.

The heatwave risk assessment highlights the need for:

- Locally adapted heatwave preparedness measures, complementing national guidance;
- Targeted protection of elderly residents, tourists, and port users;
- Consideration of night-time heat stress in early warning and response planning;
- Integration of heatwave risk into civil protection plans and public communication strategies.

### 2.3.2 Hazard #2 - River and Coastal Floods

Table 2.3b Data overview workflow #2

Hazard data	Vulnerability data	Exposure data	Impact metrics/Risk output
NOA / meteo.gr (historical weather station data for precipitation)	Demographic structure (hospitals, schools, care centres)	Residential areas, schools, public buildings, bus stops	Flood exposure hotspots; identification of buildings and critical facilities within maximum flood extent

<i>Hazard data</i>	<i>Vulnerability data</i>	<i>Exposure data</i>	<i>Impact metrics/Risk output</i>
WorldClim v2.1 high-resolution gridded data (30 arc-seconds)		Global Building Atlas (3x3 m)	
EURO-CORDEX / MED-CORDEX ensemble projections (bias-corrected)		WorldPop	
Glofas: the GFM Ensemble algorithm			

### 2.3.2.1 Hazard assessment

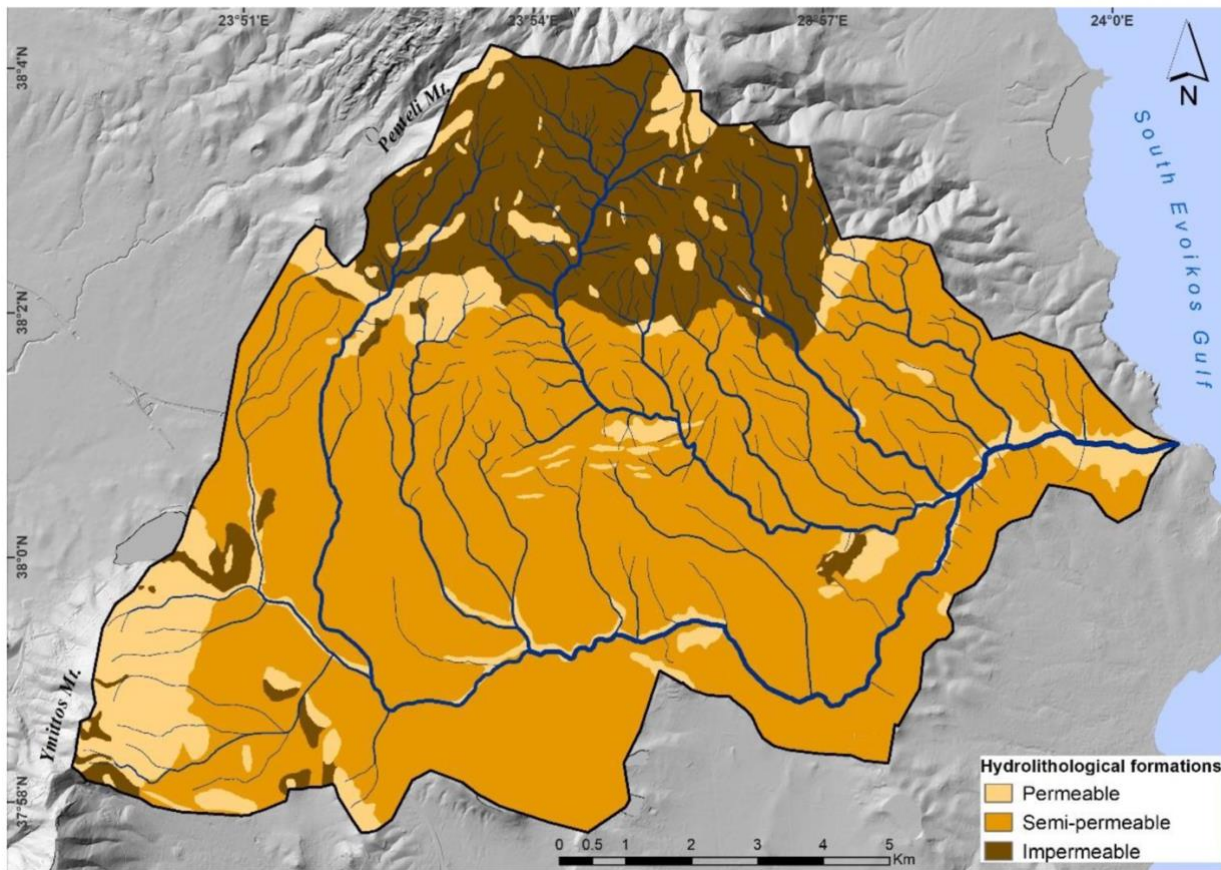
The flood hazard assessment for the Municipality of Rafina–Pikermi begins with an analysis of the hydrolithological formations and drainage structure of the Megalo Rema catchment (Fig. 2.3.2a).

The Megalo Rema watershed drains the mountainous areas of Penteli and Ymittos toward the South Evoikos Gulf, crossing the urbanized zones of Pikermi and Rafina before discharging at the coastal front. The catchment is characterized by strong elevation gradients and a dense dendritic drainage network, which promotes rapid hydrological response during intense precipitation events.

The hydrolithological map (Figure X) shows three dominant formation types:

- **Impermeable formations** (dark brown), concentrated mainly in the northern mountainous sector;
- **Semi-permeable formations** (orange), covering the majority of the mid- and lower catchment;
- **Permeable formations** (light beige), locally distributed.

The spatial predominance of impermeable and semi-permeable formations significantly limits infiltration capacity, particularly in the upper and middle catchment. As a result, the Megalo Rema system exhibits a **flashy hydrological regime**, with steep rising limbs and limited buffering capacity. The combination of lithological impermeability and increasing anthropogenic surface sealing creates conditions conducive to flash flooding during convective Mediterranean storm events.



**Fig. 2.3.2a** Hydrolithological formations of the Rafina–Pikermi area highlighting formations associated with increased runoff potential in Megalo Rema catchment. (Source: Karymbalis et al., 2021)

To quantify future precipitation extremes over Rafina–Pikermi, the CLIMAAX Heavy Rainfall workflow was applied using bias-adjusted climate projections under RCP4.5 for the mid-century period (2041–2070). The workflow estimates intensity–duration–frequency (IDF) relationships and their projected changes relative to the historical baseline (1976–2005).

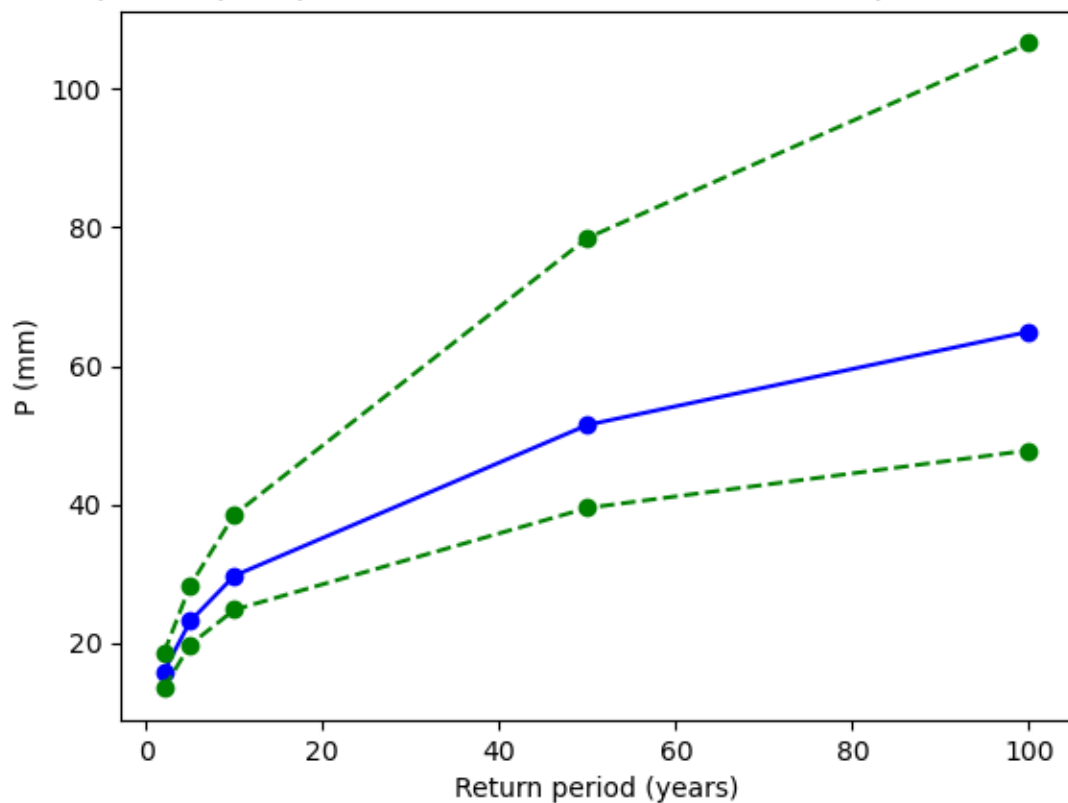
The projected intensification of sub-daily precipitation is shown in Fig. 2.3.2b. For 3-hour storm events, precipitation totals increase substantially across all return periods.

Indicative values for 2041–2070 suggest:

- ~28–30 mm for 5-year return period
- ~50 mm for 50-year return period
- 65 mm for 100-year return period

Compared to baseline values, this corresponds to increases on the order of 15–35%, particularly for higher return periods. The amplification of short-duration extremes is critical for Megalo Rema, given its steep slopes and short time of concentration, which make the basin highly responsive to convective storms.

Expected precipitation for 3h event for 2041-2070 period in Rafina.



**Fig. 2.3.2b** Expected precipitation for 3-hour events (2041–2070, RCP4.5) over Rafina–Pikermi. Projected intensity–duration–frequency (IDF) curves derived from the CLIMAAX Heavy Rainfall workflow.

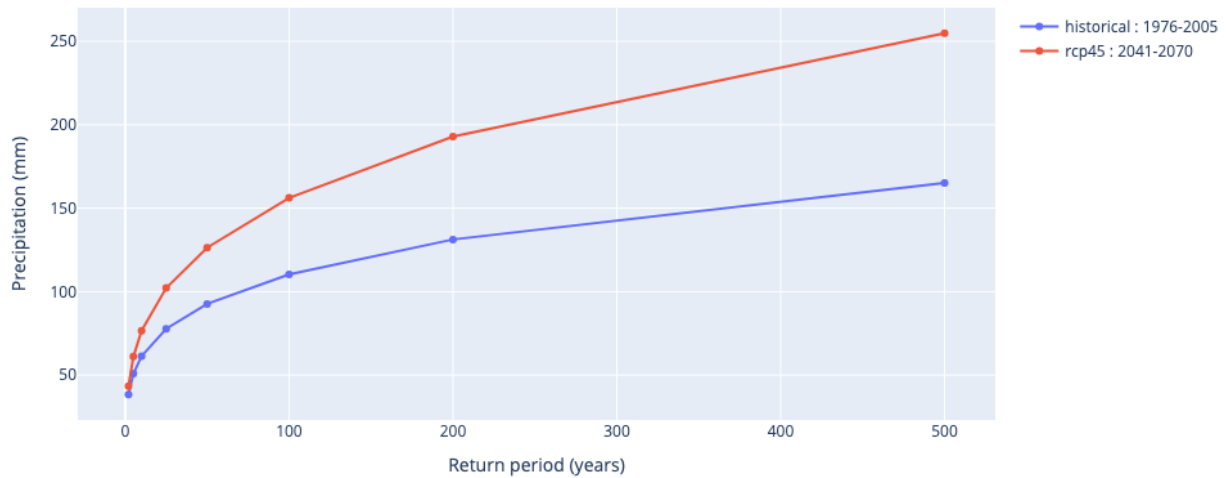
The projected intensification becomes even more pronounced for 24-hour rainfall accumulations (Fig. 2.3.2c).

Under RCP4.5 (2041–2070):

- 10-year event: ~75 mm → ~100 mm
- 50-year event: ~125 mm → ~155 mm
- 100-year event: ~150 mm → ~190 mm
- 500-year event: exceeding 250 mm

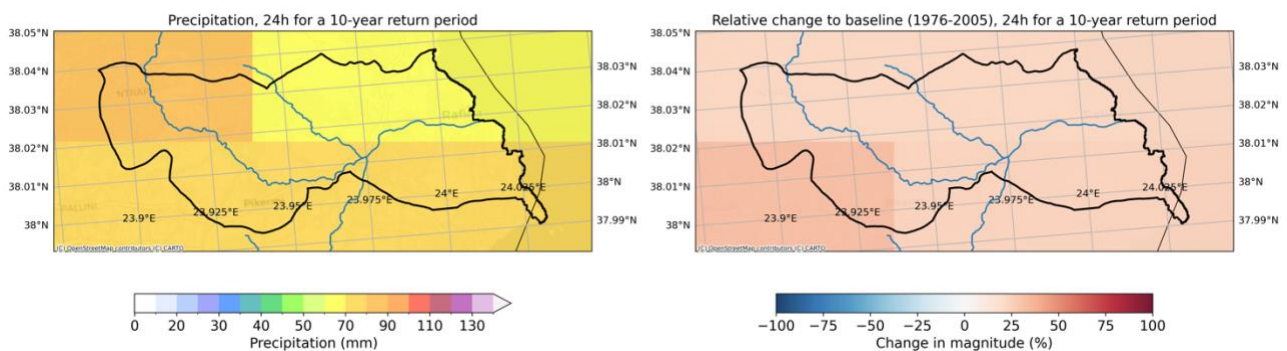
These changes represent systematic upward shifts of the entire IDF curve.

Mean precipitation for 24h duration events over Rafina-Pikermi.



**Fig. 2.3.2c** Mean precipitation for 24-hour duration events under historical (1976–2005) and RCP4.5 (2041–2070) scenarios. Comparison of IDF curves demonstrates substantial increases in 24-hour extreme rainfall totals across all return periods, with the largest absolute increases observed for high-return-period events ( $\geq 100$  years).

The relative change map for the 24-hour 10-year return period (Fig. 2.3.2d) shows spatial increases ranging approximately between 10% and 30% across the municipality, with higher intensification in inland sectors.



**Fig. 2.3.2d** Projected precipitation (24-hour, 10-year return period) and relative change under RCP4.5 (2041–2070). Left: Spatial distribution of projected precipitation totals (mm). Right: Relative percentage change compared to baseline (1976–2005).

Observed precipitation records from National Observatory of Athens (NOA) stations at Rafina and Pallini confirm the occurrence of high-intensity rainfall events in the recent past.

For example:

- 50.8 mm recorded on 22 October 2015 at Rafina
- 52.8 mm recorded on 28 November 2016 at Pallini

- 70.6 mm recorded on 29 September 2018 at Pallini
- 49.8 mm recorded on 28 July 2018 at Pallini

These observations demonstrate that extreme daily rainfall events exceeding 50–70 mm are already part of the local climatology. When considered alongside the projected upward shift in IDF curves, this indicates that future “moderate” events may resemble today’s high-impact extremes.

Although the CLIMAAX River Flood and Discharge workflows were evaluated also in Phase 1, they were not considered adequate for detailed hazard quantification in Rafina–Pikermi for the following reasons:

1. Megalo Rema is not resolved at the continental hydrological model scale. The catchment is too small and hydrologically localized to be explicitly represented in large-scale river routing datasets.
2. Coarse spatial resolution. The workflows operate at grid scales that do not capture:
  - Channel confinement in urban Rafina,
  - Local hydraulic bottlenecks,
  - Micro-topographic controls.
3. Absence of calibrated local hydrometry. There are no long-term discharge measurements for Megalo Rema to calibrate or validate modeled hydrographs.

As a result, the river flood workflow underestimates local flash-flood potential and does not “see” the hydrological response of the Megalo Rema system. Therefore, the hazard assessment relies primarily on:

- Hydrolithological runoff potential analysis,
- IDF-based extreme precipitation projections,
- Observed station data,
- Historical flood documentation.

This approach provides a physically defensible and locally relevant hazard characterization.

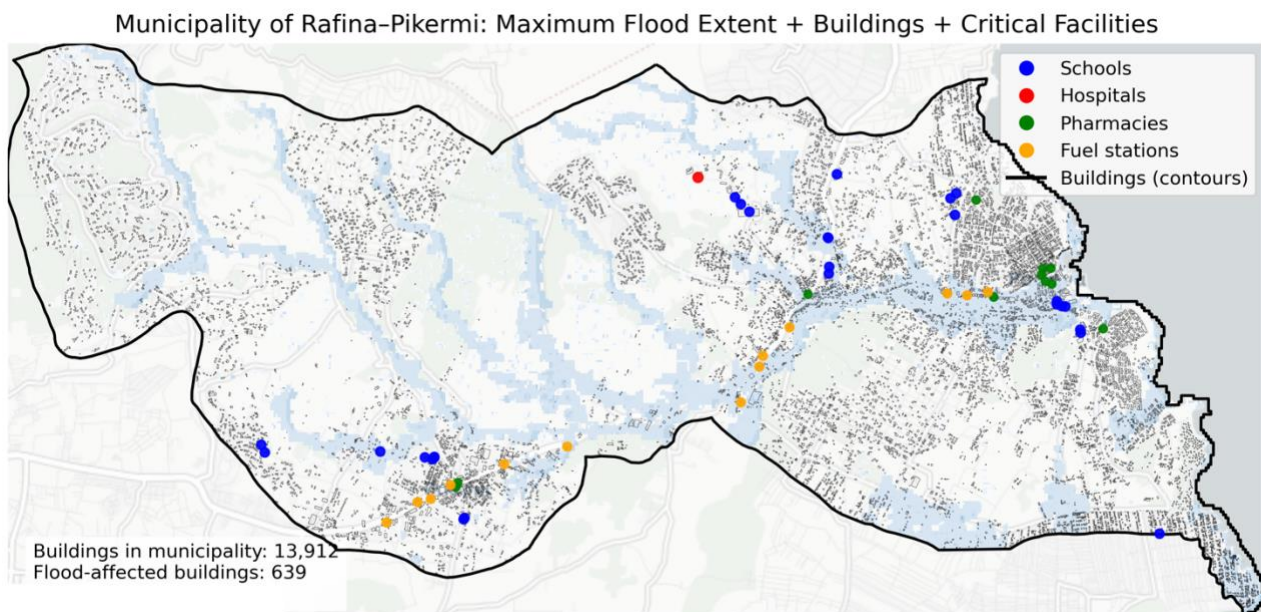
### 2.3.2.2 Risk assessment

Flood risk was assessed by intersecting the maximum flood extent derived from the Global Flood Monitoring (GFM) product with the building footprint database and critical facilities layer of the Municipality of Rafina–Pikermi.

The maximum flood extent was derived from the GFM output layer – Likelihood Values from GloFAS, which represents the spatial extent of flooding detected through the GFM Ensemble flood mapping algorithm. The Likelihood Value corresponds to the confidence level of flood classification accuracy for each Sentinel-1 grid cell outside the GFM Exclusion Mask.

The GFM Ensemble algorithm integrates flood detection outputs from three independent algorithms (LIST, DLR and TUW). Each algorithm computes pixel-level flood likelihood based on Sentinel-1 backscatter signal characteristics, and the ensemble framework combines these into a final probabilistic flood classification per grid cell. Thus, the Likelihood Value does not represent return period probability, but classification confidence of flood presence.

For the purposes of this assessment, the union of grid cells classified as flooded under high-likelihood conditions was used to approximate the maximum observed flood footprint affecting the Megalo Rema corridor and adjacent urban areas.



**Fig. 2.3.2e** Maximum flood extent derived from GFM Likelihood Values overlaid with buildings and critical facilities in Rafina–Pikermi. The flood footprint corresponds to areas classified as flooded by the GFM Ensemble flood mapping algorithm based on Sentinel-1 imagery. Black contours represent building footprints. Colored markers indicate schools (blue), hospitals (red), pharmacies (green), and fuel stations (orange).

Spatial intersection analysis indicates:

- Total buildings in municipality: 13,912
- Buildings within maximum flood extent: 639
- Percentage of exposed building stock: ~4.6%

Additionally:

- 7 schools fall within the maximum flood footprint.

The exposed buildings are primarily concentrated:

- Along the Megalo Rema channel corridor,
- In low-lying sectors of Rafina urban center,

- In transitional zones between semi-permeable upland areas and confined downstream valley reaches.

The presence of educational facilities within flood-prone areas increases social vulnerability due to:

- Daytime population concentration,
- Limited evacuation flexibility,
- Dependence on safe access routes.

While the percentage of exposed buildings appears moderate at the municipal scale, the spatial concentration of exposure along the drainage axis implies high localized flood risk intensity.

Given:

- The projected intensification of extreme precipitation (Section 2.3.2.1),
- The hydrolithological runoff amplification potential,
- The confined morphology of the downstream channel,

future events of equal meteorological magnitude are likely to produce:

- Larger inundation extents,
- Increased flood depth,
- Greater structural damage probability.

The 639 currently exposed buildings should therefore be interpreted as a minimum exposure baseline under present hydraulic behavior, rather than a ceiling estimate for future climate conditions.

Beyond residential exposure, the intersection analysis reveals that:

- 7 schools are located within the flood footprint,
- Multiple fuel stations and pharmacies are situated adjacent to flood-prone corridors (as shown in Fig. 2.3.2e).

Flooding of such facilities introduces cascading risk components:

- Disruption of emergency services,
- Fuel contamination hazards,
- Public health impacts,
- Temporary loss of educational infrastructure.

These elements significantly increase systemic vulnerability beyond direct property damage.

### 2.3.3 Additional assessments based on local models and data

#### 2.3.3.1 Hazard assessment

For flood hazard, an empirical rainfall threshold analysis was conducted using observed precipitation records from the Rafina and Pallini meteorological stations (2014–2023). Maximum recorded daily precipitation reached 70 mm in Rafina and 109 mm in Pallini during the observation period. These magnitudes are consistent with rainfall levels typically associated with pluvial and small-catchment flooding in Mediterranean environments. The empirical evidence confirms that rainfall intensities capable of triggering flood events have already occurred under present climatic conditions, reinforcing the plausibility of modeled return-period scenarios.

For heatwave hazard, local station data were used to complement regional climate projections. Observed data reveal an average of approximately 9 extreme hot days per year ( $T_{\max} > 35^{\circ}\text{C}$ ) inland and approximately 3 days per year in coastal Rafina, along with approximately 82 tropical nights ( $T_{\min} > 20^{\circ}\text{C}$ ) annually across both stations. These observations provide a locally validated baseline against which projected changes were interpreted. The combination of observed exceedance statistics with projected ensemble-based changes ensures that hazard amplification is evaluated relative to actual current exposure rather than abstract climatological averages.

The additional local assessments therefore strengthen the hazard characterization by anchoring model outputs to observed conditions and by incorporating spatially detailed hydrological information. This integrated approach reduces uncertainty associated with purely large-scale datasets and ensures that hazard identification reflects the specific climatic and geographical context of Rafina–Pikermi.

#### 2.3.3.2 Risk assessment

##### - Flood Loss and Damage Assessment

The flood loss assessment for the Municipality of Rafina–Pikermi was conducted using a building-level exposure approach based on the maximum flood extent raster and the Global Building Atlas footprint dataset. The Global Building Atlas was selected instead of OpenStreetMap due to its substantially higher building coverage and better correspondence with satellite imagery in the study area (see Figure 3-8 in Phase 1 deliverable). This choice ensured a more realistic representation of the exposed built environment and avoided systematic underestimation of exposure.

A total of 13,912 buildings were identified within the municipal boundary. Overlay analysis between building footprints and the modeled maximum flood extent resulted in 639 buildings classified as flood-affected, representing approximately 4.6% of the total building stock within the municipality.

The exposed building footprint statistics for the 639 affected buildings were as follows:

- Mean footprint area: 273 m<sup>2</sup>
- Median footprint area: 166 m<sup>2</sup>
- 10th percentile: 68 m<sup>2</sup>
- 90th percentile: 416 m<sup>2</sup>
- Minimum: 9.7 m<sup>2</sup>
- Maximum: 9,527 m<sup>2</sup>
- Total exposed footprint area: 174,443 m<sup>2</sup>

The large range reflects a mix of residential structures and a small number of large-footprint buildings.

Due to the absence of a spatially explicit water depth raster at the time of initial analysis, a conservative uniform structural damage ratio of 10% was adopted for exposed buildings. This assumption reflects minor-to-moderate structural damage affecting ground-floor components and is intentionally conservative to avoid overestimation in the absence of depth–damage curves.

Unit replacement costs (€/m<sup>2</sup>) were derived from the official Greek objective property values (Αντικειμενικές Αξίες Ακινήτων) as published by the Independent Authority for Public Revenue (AADE) through the national valuation map platform (<https://maps.gsis.gr/valuemaps/>). The applicable zone values for Rafina–Pikermi range between €1,100 and €1,950 per m<sup>2</sup> and were used to define the unit value band in the loss estimation.

Two complementary loss estimation methods were applied:

#### 1. Method 1 – Aggregate Footprint Approach (Total Area-Based)

Using the total exposed footprint area: Loss=174,443 m<sup>2</sup>×1,525 €/m<sup>2</sup>×0.10

Estimated structural loss: ≈€26.6 million

This method captures the full distribution of exposed building sizes.

#### 2. Method 2 – Median Building Approach (Representative Building-Based)

Using the median building footprint: Loss=166 m<sup>2</sup>×639 buildings×1,525 €/m<sup>2</sup>×0.10

Estimated structural loss: ≈€16.2 million

This method reduces sensitivity to large-footprint outliers

#### 3. Probabilistic Loss Band

To reflect unit value uncertainty (€1,100–€1,950/m<sup>2</sup>), the total-area method yields:

- Lower bound (1,100 €/m<sup>2</sup>):  
≈ €19.2 million

- Upper bound (1,950 €/m<sup>2</sup>):  
≈ €34.0 million

Therefore, the plausible structural loss range under the assumed 10% damage ratio is:  
€19–34 million

Central estimate: €26–27 million

In summary:

- Approximately 1 in 22 buildings in the municipality fall within the modeled flood extent.
- Even under a conservative 10% damage ratio, direct structural losses are substantial.
- The results are sensitive to:
  - Unit value assumptions
  - Damage ratio
  - Flood depth (currently not applied)
- Loss estimates exclude:
  - Contents damage
  - Business interruption
  - Infrastructure damage
  - Indirect economic impacts

The estimates should therefore be interpreted as conservative first-order direct structural losses.

#### - Historical Flood Events

To complement the return-period-based flood modelling, a local rainfall threshold analysis was performed following the CLIMAAX Extreme Precipitation workflow methodology. The objective was to identify empirical precipitation levels historically associated with documented flood events in the Rafina–Pikermi area.

A database of known flood events was compiled from municipal records and national sources. For each event, the corresponding daily precipitation totals recorded at the nearest meteorological station were extracted. The analysis focused on 24-hour accumulated rainfall, as this duration is most strongly associated with pluvial and small-catchment fluvial flooding in Mediterranean environments.

The historical event dataset in Table 2.3.3 shows that flood occurrence has been associated with daily precipitation totals ranging from 48 up to 130 mm in 24 hours in Rafina.

Table 2.3.3: Known Flood Events in Rafina–Pikermi Municipality

DATE	ACCUMULATIONS REGISTERED (MM/HRS)	GENERAL DESCRIPTION	RISK TO PEOPLE	DAMAGE TO BUILDINGS	DISRUPTION OF TRANSPORT	OTHERS / COMMENTS
22–23 OCT 2019	119 mm/24 h 81 mm/12 h 60 mm/1 h	Widespread flooding in community	Several trapped in vehicles; rescues by authorities	Underground parking & lower floors flooded	Main roads closed due to surface flooding	~140 calls to 112 with localized flooding/rescues
LATE OCT / NOV 2008–2009 (MULTIPLE)	Not specified	Multiple stream flood episodes recorded in Rafina catchment (era5 & ground data)	Not specified	Yes	Yes	Multiple local media reports of deep flooding, transportation disruption and flooded infrastructure.
11 DEC 2011	Not specified	Part of stream flooding episodes in Rafina catchment	Yes	Yes, significant	Yes	Identified as one of the significant flood episodes in research period (2008–2014)
2 & 3 NOV 2009	Not specified	Flash floods in upper basin	Not specified	Yes	Not specified	Synoptic forcing & soil moisture preconditioning contributed
11 JUN 2022	61 mm/24 h	Flash flood in Rafina	No	No	Yes	Severe convective storm with hail
25–26 MAY 2025	48 mm/24 h	Severe convective storm produced flash floods in Rafina–Pikermi region	Roads inundated; water rescues (~17 calls)	Homes and shops flooded (Evoikou, Dioni)	Bridge at Varda over Great Rafina Stream impassable; major roads closed	Multiple local media reports of deep flooding, transportation disruption and flooded infrastructure
21 JAN 2026	130 mm/24 h	Severe convective storm	Roads inundated; water rescues	Homes and shops flooded	Yes	Multiple local media reports of deep flooding, transportation disruption and flooded infrastructure

## 2.4 Key Risk Assessment Findings

The multi-hazard risk assessment conducted for the Municipality of Rafina–Pikermi identifies flood risk and heatwave risk as the dominant climate-related threats over the coming decades. The analysis combines observed meteorological data, regional climate projections, hydraulic modelling outputs, and building-level exposure assessment to provide an integrated evaluation of hazard evolution and potential impacts.

The flood hazard assessment indicates that a non-negligible portion of the municipal building stock is located within the modelled maximum flood extent. Out of 13,912 buildings identified within the municipal boundary using the Global Building Atlas dataset, 639 buildings (approximately 4.6%) intersect the simulated flood zone. The total exposed building footprint amounts to 174,443 m<sup>2</sup>, with a mean footprint of 273 m<sup>2</sup> and a median footprint of 166 m<sup>2</sup>. Even under a conservative uniform structural damage ratio of 10%, and using officially established Greek objective property values (Αντικειμενικές Αξίες Ακινήτων) ranging between €1,100 and €1,950 per m<sup>2</sup>, the estimated direct structural loss lies between approximately €19 million and €34 million, with a central estimate of approximately €26–27 million. These figures exclude contents damage, infrastructure losses, indirect economic disruption, and cascading impacts, and therefore represent a conservative lower-bound estimate of direct building damage.

The flood modelling results are further supported by empirical rainfall threshold analysis. Observed maximum daily precipitation values (70 mm in Rafina and 109 mm in Pallini during 2014–2023) demonstrate that rainfall magnitudes capable of triggering significant pluvial and fluvial flooding have already occurred in the recent climate. The integration of historical event analysis with hydraulic modelling strengthens the credibility of the flood hazard characterisation and confirms that the simulated return-period events represent physically plausible scenarios under current climate variability.

In parallel, the heatwave hazard assessment shows that the municipality is already experiencing significant thermal stress. Observed data from 2014–2023 indicate that Pallini experiences on average 9.2 days per year with T<sub>max</sub> exceeding 35°C, compared to 2.9 days per year in coastal Rafina. However, both locations experience approximately 82 tropical nights (T<sub>min</sub> > 20°C) per year, demonstrating limited nocturnal cooling across the area. Mean summer (JJA) daily maximum temperatures reach 31.5°C inland and 29.4°C along the coast, with extreme summers such as 2021 and 2023 exceeding these averages substantially.

Climate projections indicate that this heat stress will intensify significantly. Under the SSP2-4.5 scenario, mean summer maximum temperature is projected to increase by approximately 1.1°C by 2021–2040, 2.3°C by 2041–2060, and up to 3.5°C by 2061–2080 relative to the historical baseline. Med-CORDEX ensemble projections further indicate that this background warming translates into approximately 10–13 additional days per year

exceeding 35°C in the near term and more than 20 additional days by mid-century. Tropical nights are projected to increase by 12 to 25 additional nights per year over the same time horizons. By mid-century, inland areas could experience 20–25 extreme hot days annually, while the number of tropical nights may exceed 100 per year across the municipality. This represents a structural shift in the local heat regime rather than isolated extreme events.

The combined findings indicate that Rafina–Pikermi faces a dual climate risk trajectory: significant present-day flood exposure with measurable direct economic losses, and rapidly intensifying heatwave hazard driven by both mean warming and non-linear amplification of extremes. Flood risk manifests through spatially concentrated but economically substantial impacts, while heatwave risk manifests through widespread and cumulative thermal stress affecting public health, infrastructure performance, and energy demand.

Importantly, both hazards show evidence of amplification under future climate scenarios. Flood-triggering rainfall intensities are consistent with observed extreme precipitation records, and projected temperature increases are consistent across independent climate datasets. The coherence between observed data, statistical projections, and regional climate model ensembles increases confidence in the robustness of the findings.

Overall, the key conclusion of the risk assessment is that while flood impacts are episodic and spatially concentrated, heatwave impacts are chronic, intensifying, and municipality-wide. Strategic adaptation planning must therefore address both structural flood resilience measures and systemic heat mitigation strategies, particularly for vulnerable populations and critical infrastructure.

#### 2.4.1 Mode of engagement for participation

The Key Risk Assessment was informed by stakeholder engagement and participation processes described in Section 2.1.5, including workshops, meetings, and consultations with municipal services, civil protection actors, sectoral stakeholders, and representatives of vulnerable groups.

Stakeholders were engaged through:

- Presentation of Phase 1 and Phase 2 risk assessment findings;
- Structured discussion of flood and heatwave risks using qualitative severity–urgency–capacity criteria;
- Exchange of views on perceived risks, response challenges, and priority needs.

The CLIMAAX evaluation dashboard was used as a supporting tool to facilitate discussion, comparison of risks, and identification of priorities, rather than as a purely technical scoring exercise.

Feedback gathered during engagement activities highlighted strong convergence between analytical findings and stakeholder experience, particularly regarding:

- The critical role of hydraulic bottlenecks and bridge crossings in flood risk;
- The growing burden of heat stress during summer, especially at night;
- The vulnerability of elderly residents and tourists;
- The operational challenges faced during peak tourism periods and extreme weather events.

Stakeholders emphasised the need for:

- Clear prioritisation of risk areas;
- Improved coordination between municipal services, port authorities, and emergency responders;
- Practical, locally adapted guidance for heatwave preparedness.

Stakeholder feedback was used to:

- Validate the prioritisation of flood and heatwave risks;
- Refine interpretation of risk severity and urgency;
- Identify gaps in response capacity, particularly for heatwaves;
- Ensure that the Key Risk Assessment reflects real operational constraints and needs.

#### 2.4.2 Gather output from Risk Analysis step

The Risk Analysis step consolidates the outputs of the hazard characterization, exposure mapping, and damage estimation into an integrated assessment of climate risk for the Municipality of Rafina–Pikermi. The outputs presented in this section synthesize quantitative indicators derived from the flood and heatwave analyses and translate them into risk-relevant metrics suitable for decision-making.

For flood risk, the analysis combined the maximum flood extent raster with the Global Building Atlas footprint dataset to quantify exposed assets. Within the municipal boundary, 13,912 buildings were identified, of which 639 buildings intersect the simulated flood extent. This corresponds to approximately 4.6% of the total building stock. The exposed footprint area amounts to 174,443 m<sup>2</sup>. Using officially established Greek objective property values (Αντικειμενικές Αξίες Ακινήτων) ranging between €1,100 and €1,950 per m<sup>2</sup>, and assuming a conservative structural damage ratio of 10%, the estimated direct structural losses range between approximately €19 million and €34 million, with a central estimate of approximately €26–27 million. These values represent first-order direct building damage and exclude indirect, infrastructural, and socio-economic cascading impacts. The spatial concentration of exposure indicates localized but economically significant flood risk.

The rainfall threshold analysis complements the hydraulic modelling by linking documented flood events to empirically observed daily precipitation totals. Observed maximum daily

precipitation values (70 mm in Rafina and 109 mm in Pallini during 2014–2023) confirm that rainfall intensities capable of triggering pluvial and fluvial flooding have already occurred under current climate variability. This empirical consistency strengthens confidence in the modeled flood scenarios and indicates that return-period-based hazard estimates are physically plausible.

For heatwave risk, the analysis integrates observed station data with regional climate model projections. Current conditions already demonstrate substantial thermal stress, with approximately 82 tropical nights per year and an average of 2.9 to 9.2 extreme hot days (>35°C) annually, depending on inland versus coastal location. Climate projections indicate that mean summer maximum temperature will increase by approximately +1.1°C by 2021–2040, +2.3°C by 2041–2060, and up to +3.5°C by 2061–2080 under SSP2-4.5. This background warming translates into a projected increase of 10–13 additional extreme hot days per year in the near term and more than 20 additional days by mid-century. Tropical nights are projected to increase by 12 to 25 additional nights per year, potentially exceeding 100 nights annually by mid-century. The heat hazard therefore evolves from episodic extreme events to a structurally elevated thermal stress regime affecting the entire municipality.

When synthesizing hazard intensity, exposure distribution, and projected climate amplification, the risk analysis reveals two distinct but complementary risk profiles. Flood risk is spatially concentrated but associated with high direct economic losses per event. Heatwave risk is spatially widespread and cumulative, affecting the entire population and critical infrastructure over extended seasonal periods. While flood impacts are primarily asset-based and episodic, heat impacts are systemic and persistent, influencing health, energy demand, and infrastructure performance.

The combined output of the Risk Analysis step indicates that both hazards exhibit increasing risk under future climate conditions. Flood-triggering rainfall intensities remain within the range of observed extremes, suggesting continued event plausibility, while heatwave frequency and intensity are projected to increase substantially and consistently across independent climate datasets. The coherence between observed data, statistical thresholds, and ensemble projections enhances the robustness of the assessment.

Overall, the Risk Analysis step confirms that Rafina–Pikermi faces measurable present-day flood exposure with significant economic implications, alongside rapidly intensifying heatwave hazard that will increasingly dominate long-term climate risk. These outputs provide the quantitative foundation for prioritizing adaptation planning, resilience investments, and early warning strategies in subsequent stages of the CLIMAAX workflow.

### 2.4.3 Assess Severity

Risk severity was assessed for both current and future conditions in accordance with the CLIMAAX Key Risk Assessment Protocol, using the four qualitative categories limited,

moderate, substantial, and critical. The assessment considers historical experience, current observed trends, future projections, and stakeholder perspectives, and focuses on the magnitude of potential impacts rather than their timing.

- Severity of river and coastal flood risk

River and coastal flooding in the Municipality of Rafina–Pikermi is assessed as having substantial to critical severity, both under current conditions and in future climate scenarios.

Historical flood events associated with Megalo Rema have already demonstrated the potential for significant material damage, disruption of mobility, and risk to human safety. Local analyses show that flood impacts are spatially concentrated but severe, particularly in areas where dense urban development, critical infrastructure, and hydraulic constraints coincide.

Stakeholders consistently emphasised concern regarding the frequency and persistence of flooding along Megalo Rema, noting that flood risk remains high despite works carried out over previous decades. Particular concern was expressed regarding aging bridge structures, which are perceived as insufficiently designed to accommodate current and future flood flows and are seen as major contributors to overflow and localised flooding.

From a severity perspective, flood risk is further amplified by the potential for cascading and irreversible impacts, including:

- Damage to residential and commercial areas;
- Disruption of emergency access and evacuation routes;
- Economic losses affecting port operations, tourism, and local businesses;
- Degradation of riverine ecosystems and loss of natural flood attenuation capacity.

Stakeholders also stressed that past proposals to redirect floodwaters away from the natural river course could significantly increase severity by transferring risk to other areas and undermining the river's capacity to convey water safely to the sea. Similarly, the removal of vegetation from the river bed and banks was highlighted as a factor that may increase flow velocities, reduce ecological stability, and exacerbate downstream impacts.

Considering the scale of potential damage, the concentration of exposed assets, and the risk of irreversible ecological and functional consequences, flood risk is assessed at the upper end of the severity spectrum, approaching critical under unfavourable conditions.

- Severity of heatwave risk

Heatwave risk in Rafina–Pikermi is assessed as substantial, with the potential to become critical under prolonged or compound heat events.

While heatwaves may not always result in immediate, visible damage to infrastructure, their severity is expressed through public health impacts, cumulative physiological stress, and increased mortality risk, particularly among vulnerable groups. Local analyses demonstrate that night-time tropical conditions significantly increase heat stress severity by preventing recovery between successive hot days.

The severity of heatwave impacts is heightened by:

- The presence of elderly populations and individuals with chronic health conditions;
- High seasonal population peaks linked to tourism and port activity;
- Exposure of non-acclimatised visitors and outdoor workers.

Stakeholders and experts acknowledged that heatwave impacts are often underestimated, particularly when night-time conditions are not explicitly considered. This contributes to a perception gap that may mask the true severity of heat-related risks.

Stakeholder engagement enriched the severity assessment by grounding analytical results in operational experience and local knowledge. Participants demonstrated a strong understanding of flood severity drivers, particularly structural constraints and ecosystem degradation, while also recognising growing heat-related health risks.

However, discussions also revealed that decision-makers and practitioners are more familiar with flood impacts than with heatwave-related severity, especially regarding cumulative and night-time heat stress. This highlights the need for continued capacity building and awareness-raising to ensure that severity assessments fully inform decision-making.

Based on the combined analysis of technical evidence and stakeholder input:

- Flood risk is assessed as substantial to critical, due to high impact potential, cascading effects, and risk of irreversible damage.
- Heatwave risk is assessed as substantial, with potential escalation toward critical severity under prolonged or compound events.

These severity levels justify the prioritisation of both risks in the Key Risk Assessment and support the need for targeted, locally adapted risk management and civil protection measures.

#### 2.4.4 Assess Urgency

- Future escalation of urgency due to sea-level rise and port-area exposure

An additional factor significantly increasing the urgency of flood risk management in Rafina–Pikermi is the interaction between future sea-level rise, port-area land use, and riverine flooding at the outlet of Megalo Rema.

Phase 1 of the Climate Risk Assessment identified that projected sea-level rise is expected to affect low-lying coastal areas within the port zone, including the large passenger parking area located immediately adjacent to the mouth of Megalo Rema. This area represents a critical exposure hotspot, as it combines:

- proximity to the river outlet,
- low elevation relative to mean sea level,
- and high seasonal concentration of people and vehicles.

The Phase 2 assessment confirms that this exposure is not adequately addressed in existing planning documents, including the Port Master Plan published in 2024, which is provided in the Supporting documentation. While the Master Plan considers port development and operational needs, it does not explicitly account for future sea-level rise and its interaction with river discharge during flood events, nor for the implications for adjacent parking and access areas.

This planning gap increases urgency, as future conditions may:

- Reduce drainage efficiency at the river mouth;
- Increase the likelihood of compound river–coastal flooding;
- Lead to rapid inundation of the port parking area during extreme events;
- Create safety risks for passengers, vehicles, and emergency access, particularly during peak tourist periods.

Given the strategic importance of the port and its role as a major passenger hub, the exposure of this parking area represents a time-sensitive risk that requires early integration into civil protection planning, even if structural adaptation measures are implemented gradually.

The identification of this issue across Phase 1 and Phase 2 highlights the need to anticipate future risk escalation, rather than relying solely on current hazard conditions. As a result, the presence of critical, low-lying port infrastructure adjacent to Megalo Rema reinforces the classification of flood risk as requiring immediate action, particularly with respect to preparedness, emergency planning, and access management under adverse coastal and hydrological conditions.

- Urgency of river flood risk

River flooding in Rafina–Pikermi is assessed as requiring immediate action.

Flood events associated with intense rainfall have already occurred under current climate conditions, and stakeholders consistently report recurrent flooding along Megalo Rema, including in recent years and despite past mitigation works. This indicates that flood risk is not a future-only concern, but an ongoing and active threat.

From an urgency perspective, flood risk is characterised by:

- Sudden-onset events, often triggered by short-duration, high-intensity rainfall;
- Limited warning time, which constrains preparedness and emergency response;
- The presence of aging and hydraulically inadequate bridge structures, which increase the likelihood of rapid overflow and localised flooding.

Stakeholders emphasised that delays in addressing these structural and hydraulic constraints increase the probability of severe impacts during future events. The potential for ongoing works along Megalo Rema to temporarily alter river conditions further heightens urgency, as flood behaviour may change dynamically in the near term.

Future climate projections and recent trends suggest an increase in the intensity of extreme rainfall events, which may further elevate flood risk even if total annual rainfall does not increase significantly. This implies that both current and near-future urgency levels are high, and that postponing action would likely result in avoidable damage.

Given the combination of current impacts, sudden onset, limited response time, and high exposure of people and infrastructure, flood risk clearly falls within the “immediate action needed” category.

- Urgency of heatwave risk

Heatwave risk in Rafina–Pikermi is assessed as requiring more action needed, with a clear trajectory toward immediate action needed if current trends continue.

Heatwaves are already occurring regularly during summer months, and local observations indicate an increase in the frequency and persistence of heatwave conditions, particularly night-time tropical conditions. Unlike floods, heatwaves are typically slow-onset events, but their impacts accumulate over time and can escalate rapidly during prolonged episodes.

Urgency is driven by:

- The increasing number of heatwave and thermal stress days observed locally;
- The persistence of high night-time temperatures and humidity, which prevents recovery;
- The seasonal influx of tourists and port users, increasing exposure during peak summer periods.

While heatwave impacts may not always manifest immediately in visible damage, stakeholders and experts noted that health impacts and service strain are already being experienced and are likely to intensify in the near future.

The absence of dedicated local heatwave protocols further increases urgency, as response capacity is currently limited and relies primarily on national guidance that does not fully reflect local conditions.

Given these factors, heatwave risk is assessed as requiring more action needed in the immediate term, with a strong case for escalation to immediate action needed as temperatures and night-time heat stress continue to rise.

- Stakeholder perspectives on urgency

Stakeholder engagement reinforced the urgency assessment by highlighting:

- Strong concern over the frequency of flooding, even after previous interventions;
- Widespread perception that structural vulnerabilities along Megalo Rema require prompt attention;
- Growing awareness of heat-related stress, particularly for elderly residents and tourists, though with less institutional readiness to respond.

Stakeholders broadly agreed that flood risk requires immediate attention, while heatwave risk requires accelerated action to prevent it from becoming an unmanaged emergency.

- Overall urgency assessment

Based on current impacts, expected near-term trends, and stakeholder input:

- River and coastal flood risk is classified as immediate action needed.
- Heatwave risk is classified as more action needed, with a clear need to scale up preparedness rapidly.

#### 2.4.5 Understand Resilience Capacity

Resilience capacity was assessed in accordance with the CLIMAAX Key Risk Assessment Protocol, using the qualitative categories low, medium, substantial, and high. The assessment considers the municipality's existing measures, resources, and institutional arrangements to prevent, prepare for, respond to, and recover from climate-related risks, with particular focus on river and coastal flooding and heatwaves.

The assessment draws on information from the Risk Analysis step, stakeholder engagement, and review of existing plans and practices, and considers financial, human, physical, natural, and social dimensions of capacity.

Overall resilience capacity for river and coastal flooding in Rafina–Pikermi is assessed as medium, with important strengths but also critical weaknesses.

Existing measures and strengths include:

- Operational experience with flood events and emergency response;
- Established cooperation with regional civil protection authorities;
- Ongoing and completed technical works along Megalo Rema aimed at flood risk reduction;
- Availability of technical studies (hydraulic, geological, geotechnical, coastal) supporting informed decision-making.

From a human and institutional capacity perspective, municipal services and emergency responders demonstrate familiarity with flood response procedures, and stakeholders show high awareness of flood risk, particularly regarding Megalo Rema.

However, several weak spots limit overall resilience capacity:

- Aging bridge infrastructure and hydraulic bottlenecks that reduce system robustness;
- Limited redundancy in critical transport routes, increasing vulnerability to isolation;
- Insufficient integration of future drivers such as sea-level rise and compound river-coastal flooding into operational planning, particularly in the port area;
- Constraints on financial resources for large-scale structural upgrades.

From a natural capacity perspective, the ecological condition of the river corridor plays a role in attenuating flood impacts, but this capacity is vulnerable to degradation through inappropriate interventions, such as excessive vegetation removal.

Taken together, these factors indicate a moderate ability to manage current flood risk, but insufficient robustness to fully address escalating future risks without additional targeted measures.

Resilience capacity for heatwaves is assessed as low to medium, reflecting significant gaps in preparedness and response despite growing risk.

Existing measures primarily consist of:

- Reliance on national-level heatwave guidance and alerts;
- General public awareness of heat risks during summer periods;
- Presence of social services and elderly care facilities that can support vulnerable groups.

However, local capacity limitations are pronounced, particularly in relation to:

- Absence of municipality-specific heatwave protocols tailored to local conditions;
- Limited consideration of night-time heat stress and tropical nights in preparedness measures;
- Lack of (enough) dedicated cooling centres, targeted communication strategies, or heat-specific response planning;

- High exposure of tourists and port users, who are not systematically addressed in current measures.

From a human and social capacity perspective, awareness of heatwave severity is uneven, and heat risks are often perceived as less critical than flood risks, despite their significant health impacts.

Physical capacity to respond to heatwaves (e.g. shading, cooling infrastructure, heat-resilient public spaces) is limited, particularly in port and high-activity areas.

Across both risk types, several cross-cutting capacity issues influence overall resilience:

- Financial capacity is constrained, limiting the pace and scale of structural interventions;
- Planning and coordination capacity exists but requires stronger integration of climate projections into operational decision-making;
- Social capacity and inclusion are challenged by the presence of vulnerable and transient populations, such as elderly residents and tourists.

Stakeholders consistently highlighted the need for clearer prioritisation, better coordination, and locally adapted guidance, particularly for heatwaves.

The municipality has access to a growing body of technical evidence and planning tools that can support enhanced resilience, including:

- Flood hazard and risk mapping refined through CLIMAAX Phase 2;
- Port and river studies that can inform future infrastructure upgrades;
- Opportunities to integrate climate risk considerations into civil protection plans and development planning.

However, the effectiveness of these tools depends on their translation into concrete measures, such as updated emergency procedures, infrastructure adaptation, early warning enhancements, and public awareness campaigns.

Based on the above analysis:

- Resilience capacity for river and coastal flooding is assessed as medium;
- Resilience capacity for heatwaves is assessed as low to medium.

While Rafina–Pikermi demonstrates a baseline ability to respond to climate risks, current capacity is not sufficient to fully manage escalating risks, particularly under future climate conditions. Strengthening resilience capacity is therefore a priority requirement to complement the severity and urgency identified in the Key Risk Assessment.

### 2.4.6 Decide on Risk Priority

Risk prioritisation was carried out following the procedure described in the CLIMAAX Key Risk Assessment Protocol, using the Key Risk Evaluation Dashboard as a structured support tool. The process aimed to translate the analytical findings from the Risk Analysis step and the qualitative assessments of severity (Section 2.4.3), urgency (Section 2.4.4), and resilience capacity (Section 2.4.5) into clear and transparent risk priorities.

The prioritisation process consisted of the following steps:

1. Compilation of risk-specific inputs: Outputs from the Risk Analysis step (Sections 2.3.1–2.3.3) were consolidated for each major climate risk, focusing on flood and heatwave hazards. These inputs included hazard characteristics, exposure patterns, vulnerability considerations, and contextual information relevant to response capacity.
2. Qualitative scoring using the evaluation dashboard: Each risk was evaluated against the three core dimensions defined in the CLIMAAX protocol:
  - Severity (magnitude of potential impacts),
  - Urgency (need for timely action),
  - Resilience capacity (ability to manage the risk with existing measures).

The evaluation dashboard was used to support consistent scoring across risks, facilitating comparison and discussion rather than serving as a purely numerical ranking tool.

3. Integration of stakeholder perspectives: Stakeholder feedback gathered during engagement activities was used to validate and refine the prioritisation, ensuring that analytical results aligned with local experience, operational constraints, and perceived risks. This step helped identify risks that may require higher priority due to practical considerations not fully captured by technical indicators alone.
4. Expert judgement and final prioritisation: Final risk priorities were assigned through expert judgement, informed by the dashboard results and stakeholder input, and with particular emphasis on risks where high severity and urgency coincide with limited resilience capacity.

Based on this process, the following climate risks were identified as priority risks for the Municipality of Rafina–Pikermi:

- River and coastal flooding was assigned the highest priority, due to:
  - Substantial to critical severity of impacts;
  - Immediate urgency driven by recurrent events and sudden onset;
  - Medium resilience capacity with significant structural and planning gaps;
  - Potential for cascading and compound impacts, particularly in the port area and along Megalo Rema.

- Heatwaves were assigned a high priority, reflecting:
  - Substantial severity linked to cumulative heat stress and public health impacts;
  - Increasing urgency under current and near-future climate conditions;
  - Low to medium resilience capacity, particularly due to the absence of dedicated local heatwave protocols;
  - High exposure of vulnerable and transient populations, including elderly residents and tourists.

While both risks require attention, flood risk was prioritised for immediate and focused action, whereas heatwave risk was prioritised for rapid capacity building and integration into civil protection planning.

The completed Key Risk Evaluation Dashboard is provided alongside this deliverable and documents the scoring and rationale used during the prioritisation process.

Risk Workflow	Severity		Urgency	Capacity	Risk Priority
	C	F		Resilience/ CRM	
River flooding					Very High
Coastal flooding					Very High
Heatwaves					Moderate

<b>Severity</b> Critical Substantial Moderate Limited	<b>Urgency</b> Immediate action needed More action needed Watching brief No action needed	<b>Resilience Capacity</b> High Substantial Medium Low	<b>Risk Ranking</b> Very high High Moderate Low
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Fig. 2.4.6 The Key Risk Evaluation Dashboard.

## 2.5 Monitoring and Evaluation

- Lessons learned from Phase 2 and encountered difficulties

The second phase of the Climate Risk Assessment provided significant added value compared to Phase 1 by enabling a substantial refinement of risks through the use of local, high-resolution data and stakeholder input. The most important lesson learned is that risk characteristics, severity drivers, and response needs differ considerably at local scale and cannot be adequately captured using European-scale indicators alone.

Phase 2 demonstrated the importance of:

- Integrating local hydraulic, geotechnical, coastal, and meteorological data to capture compound and cumulative risks;
- Explicitly addressing night-time heat stress and compound river–coastal flooding, which were underestimated in earlier assessments;
- Translating technical risk outputs into operationally relevant information for civil protection planning.

The main difficulties encountered during Phase 2 included:

- Heterogeneity of data sources, formats, and spatial scales, requiring additional effort for interpretation and consistency;
- Limited availability of structured local datasets, particularly for exposure and vulnerability;
- Gaps between existing planning documents (e.g. port Master Plan) and future climate risk considerations, requiring careful interpretation rather than direct reconciliation.

Despite these challenges, the Phase 2 process significantly improved the robustness and relevance of the CRA.

- Role of stakeholders in Monitoring and Evaluation

Stakeholders played a central role in both the monitoring and evaluation of the CRA process and its outcomes. Their involvement ensured that analytical findings were:

- Validated against local experience and operational knowledge;
- Interpreted in light of practical constraints and institutional realities;
- Aligned with the needs of civil protection, port operations, social services, and vulnerable groups.

Stakeholder feedback confirmed that:

- Flood risk along Megalo Rema remains a dominant concern despite past works;
- Heatwave risk, particularly linked to night-time conditions, is increasingly recognised as a major challenge;
- There is strong demand for clear prioritisation and actionable guidance, rather than purely technical outputs.

Stakeholders also expressed interest in using the CRA as a living reference document, supporting periodic updates and policy decisions.

- Ensuring learning and institutional memory

Learning is ensured through:

- Documentation of methods, assumptions, and findings in this deliverable and its Supporting documentation;
- Use of the CLIMAAX Key Risk Evaluation Dashboard, which provides a repeatable and transparent framework for future reassessments;
- Integration of CRA findings into civil protection planning processes, ensuring institutional uptake beyond the project duration.

The CRA process also contributed to capacity building within the municipality by strengthening understanding of climate risks and their local manifestations.

- Data availability and future needs

Phase 2 benefited from the availability of new and locally relevant data, including:

- Local meteorological observations from NOA/meteo.gr stations;
- Hydraulic, geotechnical, geological, and coastal studies;
- Environmental Impact Assessments related to ongoing works.

However, further improvements in risk understanding would benefit from:

- Systematic monitoring of flood events, impacts, and response performance;
  - Enhanced monitoring of heat-related health indicators, particularly during night-time;
  - Improved datasets on population exposure, tourism flows, and critical infrastructure usage;
  - Continued access to evaluation tools and technical expertise.
- Communication of outcomes

Final outcomes of the CRA will be communicated through:

- This deliverable and its Supporting documentation;
- Additional targeted briefings to municipal services, civil protection authorities, and the Port Authority;
- Integration of key findings into civil protection plans, operational procedures, and public communication strategies.

Clear, non-technical summaries will be prioritised to ensure accessibility for decision-makers and the wider public.

- Monitoring systems and follow-up

While no fully integrated climate risk monitoring system is currently in place, the CRA provides a baseline framework upon which monitoring can be developed. Existing early warning systems for floods and heatwaves can be progressively enhanced and linked to:

- Identified priority risk areas;

- Vulnerable population groups;
- Port and tourism-related activities.

The CRA findings support the development of risk-informed monitoring indicators, particularly for flood frequency, heatwave persistence, and night-time thermal stress.

- What worked well and what did not

What worked well:

- Use of local data and expert knowledge;
- Stakeholder engagement throughout the process;
- Structured prioritisation using the CLIMAAX dashboard.

What did not work as well:

- Time and effort required to harmonise diverse data sources;
  - Limited availability of quantitative vulnerability data;
  - Dependence on external datasets not originally designed for CRA purposes with no desirable outcomes.
- Efficiency of resource use

Resources were used efficiently by focusing efforts on priority risks and leveraging existing studies and data. While additional time was required for data interpretation and stakeholder coordination, this investment resulted in significantly improved outcomes compared to a purely desk-based assessment.

The efficiency of the process positively impacted the CRA by ensuring that analytical depth was matched by practical relevance.

- Overall impact of the CRA

Overall, the Climate Risk Assessment has had a high positive impact on:

- Understanding of local climate risks and their drivers;
- Institutional awareness and engagement;
- Readiness to integrate climate risk considerations into planning and investment decisions.

The CRA provides a strong foundation for evidence-based adaptation, improved civil protection, and enhanced resilience in the Municipality of Rafina–Pikermi.

## 2.6 Work plan Phase 3

Phase 3 of the CLIMAAX project focuses on translating the results of the Climate Risk Assessment into concrete contributions to local adaptation strategies and improved risk management and civil protection planning for the Municipality of Rafina–Pikermi. Building on the Key Risk Assessment findings and prioritisation achieved in Phase 2, Phase 3 will emphasise implementation-oriented follow-up, stakeholder engagement, and integration into existing planning frameworks.

The main objectives of Phase 3 are to:

- Support the integration of priority climate risks into municipal civil protection and risk management plans;
- Contribute to the development of locally adapted measures addressing flood and heatwave risks;
- Strengthen institutional capacity and coordination for climate risk management;
- Ensure that CRA outcomes are translated into practical, actionable guidance for decision-makers and practitioners.

Phase 3 will include the following main activities:

- Follow-up on key risk assessment findings

The results of the Key Risk Assessment, including the prioritisation of river and coastal flooding and heatwaves, will be used as the primary entry point for Phase 3 activities. This includes:

- Reviewing how priority risks are currently addressed in existing civil protection and risk management plans;
  - Identifying gaps between assessed risks and existing preparedness, response, and recovery measures;
  - Validating priorities and proposed directions with municipal services, civil protection actors, and relevant stakeholders.
- Contribution to civil protection and risk management plans

Phase 3 will focus on supporting updates to civil protection plans by:

- Translating risk priorities into clear operational considerations, such as priority areas, vulnerable groups, and critical infrastructure;
- Supporting the incorporation of compound risk considerations, including river–coastal flooding and night-time heat stress;
- Providing input for early warning, preparedness, response, and communication measures tailored to local conditions.

Special attention will be given to:

- Flood risk along Megalo Rema and in port-adjacent areas;
- Heatwave preparedness, particularly for elderly residents, tourists, and port users.
- Identification and structuring of adaptation measures

Based on the CRA findings, Phase 3 will support the identification and structuring of potential adaptation measures, including:

- Non-structural measures such as preparedness protocols, awareness campaigns, and coordination mechanisms;
- Nature-based and ecosystem-sensitive approaches where relevant;
- Measures aimed at improving institutional readiness and response capacity, rather than detailed engineering design.

These measures will be framed to support local adaptation strategies, while remaining consistent with regional and national policy frameworks.

- Stakeholder engagement and validation

Stakeholder engagement will continue in Phase 3 through targeted workshops and consultations, with the aim of:

- Discussing proposed adaptations and risk management measures;
- Ensuring feasibility and acceptability of proposed actions;
- Strengthening ownership of outcomes among local actors.

Phase 3 will not include:

- Detailed engineering design of structural flood protection works;
- Cost–benefit analysis of large-scale infrastructure investments;
- Quantitative health impact assessments related to heatwaves.

These aspects fall outside the scope of the CLIMAAX project and require dedicated studies and resources. Instead, Phase 3 will focus on strategic, planning-level contributions that can guide future investments and detailed assessments.

By the end of Phase 3, the project will deliver:

- Clear input to local adaptation strategies addressing priority climate risks;
- Improved alignment between climate risk assessment findings and civil protection planning;
- Enhanced awareness and capacity among municipal stakeholders to manage current and future climate risks;

- A structured pathway for continued monitoring, evaluation, and future updates of the CRA.

### 3 Conclusions Phase 2- Climate risk assessment

Phase 2 of the Climate Risk Assessment for the Municipality of Rafina–Pikermi has provided a quantitative and evidence-based evaluation of the dominant climate hazards affecting the area, namely flooding and heatwaves. The assessment combined observed meteorological data, high-resolution climate projections, hydraulic modelling outputs, empirical rainfall threshold analysis, and building-level exposure and loss estimation. The integration of these datasets has enabled a structured characterization of both current risk conditions and projected future intensification.

The flood analysis demonstrates that a measurable proportion of the municipal building stock is located within the modelled flood extent. Of the 13,912 buildings identified within the municipal boundary, 639 buildings intersect the simulated flood zone, corresponding to approximately 4.6% of the total building stock. Even under conservative structural damage assumptions, direct building losses are estimated in the range of €19–34 million, with a central estimate of approximately €26–27 million. These estimates represent direct structural impacts only and exclude infrastructure damage, business interruption, and cascading socio-economic effects, indicating that total event-level impacts could be substantially higher. The empirical rainfall analysis confirms that daily precipitation magnitudes capable of triggering flooding have already occurred in the recent climate, reinforcing the plausibility of the modelled hazard scenarios.

The heatwave assessment reveals that the municipality is already exposed to substantial thermal stress, particularly during summer months. Observed data indicate recurrent extreme heat days and a high number of tropical nights, with limited nocturnal cooling even in coastal areas. Climate projections under SSP2-4.5 show consistent and progressive warming across all future periods, with mean summer temperatures increasing by approximately 1.1°C in the near term and up to 3.5°C by late century relative to historical baselines. This warming translates into a significant non-linear amplification of extreme heat indicators, including substantial increases in the annual number of days exceeding 35°C and tropical nights. By mid-century, extreme heat conditions are projected to shift from episodic events to structurally elevated seasonal conditions affecting the entire municipality.

The comparison of hazard types highlights two distinct risk dynamics. Flood risk is spatially concentrated and episodic, generating high economic losses during discrete events. Heatwave risk, by contrast, is spatially widespread and cumulative, exerting prolonged stress on public health, infrastructure systems, and energy demand. While flood impacts are asset-based and geographically bounded, heatwave impacts are systemic and increasingly persistent.

A key conclusion of Phase 2 is that both hazards demonstrate robust signals of intensification under projected climate conditions. The consistency between observed data, downscaled climate products, and regional climate model ensembles strengthens confidence in the direction and magnitude of projected change. Although uncertainties remain—particularly regarding the exact magnitude of future precipitation extremes and damage ratios—the overall risk trajectory is clearly upward for both flood and heat hazards.

The results of this phase provide a quantitative foundation for the subsequent adaptation planning stage. The identification of exposed assets, the estimation of potential economic losses, and the characterization of future hazard amplification allow for prioritization of resilience measures. Strategic adaptation in Rafina–Pikermi will require a dual approach: structural and spatial interventions to reduce flood exposure, and systemic heat mitigation and preparedness measures to address increasingly frequent and intense heatwave conditions.

Overall, Phase 2 confirms that climate risk in Rafina–Pikermi is already present, measurable, and projected to intensify. Proactive adaptation planning is therefore not precautionary but necessary to reduce future socio-economic vulnerability and enhance municipal resilience under evolving climate conditions.

## 4 Progress evaluation

*Table 4-1 Overview key performance indicators*

Key performance indicators	Progress
2 of 2 workflow successfully applied on deliverable 1	Done
2 of 2 workflow successfully applied on deliverable 2	Done
10 stakeholders involved in the activities of the project (NGOs & private organizations) April 2026	Done
>10 articles in regional media mentioning the project should be a goal July 2026	8 articles have been published until February 2026
>20h Training Hours of the project July 2026	About 10 h of training until January 2026
>150 Students / >5 NGOs involved in the trainings June 2026	Done
Stakeholder Satisfaction with Survey Score > 8 (1-10 scale) April 2026 1st Survey and July 2026 2nd Survey after	Under preparation

Key performance indicators	Progress
<i>comments, reforms and programme adaptations / Feedback Survey Score</i>	

Table 4-2 Overview milestones

Milestones	Progress
M1: Multi-risk climate assessment RVA	Done
M2: Municipal departments and Staff Engagement – CLIMAAX mission	Done
M3: Attend the CLIMAAX workshop held in Barcelona.	Done
M4: Refined regional/local multi-risk assessment	Done
M8: Presentation of the results to policy and decision makers in our region.	Under preparation / partly done so far

## 5 Supporting documentation

HIST\_JJA\_tmax\_1970-2000\_RAFINA.tif (Fig. 2.3.1a)

tr-CORDEX-EUR-11\_timeseries.csv (Fig. 2.3.1b)

DELTA\_JJA\_tmax\_2021-2040\_minus\_1970-2000\_RAFINA.tif (Fig. 2.3.1c)

tmax\_JJA\_RafinaPikermi\_2021-2040\_clipped.tif (Fig. 2.3.1d)

EXTREME\_PRECIPITATION\_Hazard\_Assessment.ipynb (Figs. 2.3.2b, 2.3.2c, 2.3.2d)

Rafina\_ExposedBuildings.gpkg (Fig. 2.3.2e)

rafina.txt (NOA weather station Rafina)

pallini.txt (NOA weather station Pallini)

EU\_E057N003T3\_ENSEMBLE\_UNCERTAINTY\_20260131T042339\_VV\_EU020M\_E057N003  
T3\_20260131.tif (Global Flood Monitoring (GFM) product – Flood likelihood)

EU\_E060N003T3\_ENSEMBLE\_UNCERTAINTY\_20260131T042339\_VV\_EU020M\_E060N003  
T3\_20260131.tif (Global Flood Monitoring (GFM) product – Flood likelihood)

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